PROJECT MAPRES

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TECHNICAL REPORT

TASK 1
Action D.1

Oil spills impacts on the coastal environment: a bibliography

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Preface

This document contains results from a bibliographic research of the existing literature dealing with oil spill accidents and the impacts of oil pollution on the coastal ecosystem.
First the report considers a list of all the major oil spills occurred in the last 30 years obtained through the analysis of different historical and statistical data and of the scientific literature. Then, it focuses on the principal accidents and their effects on different compartments of the marine and coastal environments and on the social management (biodiversity, coastal ecosystems, economy, society,…).

Due to the wideness and complexity of the existing bibliography, the research was carried out through a selection of the documents considered of main interest, on the base of the following criteria:

- Prior attention has been given to the scientific publications related to oil spills which affected European countries and in particular the Mediterranean and the North East Atlantic regions;
- Out of Europe particular attention was dedicated to *Exxon Valdez* because it is so well known both by scientists and by common people, although it is not among the twentieth largest spills;
- Besides the scientific literature, there have been indicated important web-sites where it is possible to browse and in some cases to download articles, reports, abstracts of books, proceedings and manuals related to oil spills;
- Publications about prevention, monitoring and remediation techniques which have not been applied to the above mentioned major oil spills have not been taken into account for this report as they will be object of the following action about Best Practices for mitigation and damage recovery.

At the end of the report some concluding remarks are made through the analysis of six major oil spills for what concerns the main effects on the coastal environments.

1 Introduction

Pollution of the sea surface by mineral or petroleum oil is a major environmental problem.Oil spills are, in fact, seriously affecting the marine ecosystem and cause political and scientific concern since they have serious affect on fragile marine and coastal ecosystem. The amount of pollutant discharges and associated effects on the marine environment are important parameters in evaluating sea water quality. Increased public pressure has forced national and international organizations to set up effective legislative protection of the marine and coastal environment over the last 15 to 20 years. As a result, many countries have signed the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78) which sets standards for ship discharges, allowing discharges only beyond certain distances from the nearest coast and only at very small amounts. Several sea areas have been declared as Special Areas, where ship discharges are prohibited almost completely. Such Special Areas are the Mediterranean Sea, the Baltic Sea, and the North Sea. However, despite the MARPOL convention, large quantities of mineral oil are still being discharged from ships in these Special Areas. Mineral oil floating on the sea surface does not always originate from ships. Other sources are refineries, oil terminals, industrial plants, oil platforms and seepage of natural oil from the sea bottom (Espedal and Johannessen, 2000). It is estimated that 0.25% of world oil production ends up in the ocean. However, the main contribution of oil pollution originating from transportation activities still originates not from ship accidents, but from routine ship operations like tank washing and engine effluent (mostly sludge) discharges (Lean and Hinrichsen, 1992).

The availability of liquid petroleum in the form of crude oil and its refined products is a key driver for all sorts of activities in modern society, but its widespread use also inevitably results in accidental and intentional releases. Oil slick is a marine pollution receiving much attention all over the world due to its frequency of occurrence, magnitude and the extent of damage it can inflict on the environment. The impact of an accidental oil spill is primarily perceived as a major environmental problem, but associated socio-economic effects also play an important role. The extent of these impacts is likely to be determined by a diverse set of factors (e.g. Etkin, 1999; NRC, 2003; McCay et al., 2004): (1) the amount, rate and type of oil spilled; (2) the location that comprises geographical position as well as political and legal issues; (3) the vicinity to sensitive resources; (4) the choice and effectiveness of cleanup strategies (Burgherr, 2007).

1.1 Composition and Physical properties of oil

The term oil describes a broad range of hydrocarbon-based substances. Crude oils are composed of many thousands complex gaseous, liquid and solid organic compounds of which hydrocarbons are the most abundant (Kennish, 1992). Important constituents are the alkanes (parrafins), cycloalkanes (cycloparrafins, naphtalenes), alkenes, alkynes and the aromatic hydrocarbons including polynuclear or polycyclic hydrocarbons (PAHs). This last group (aromatics with low boiling points) forms the most toxic part of the oil and generally the toxicity increases from alkanes, cycloalkanes and alkenes to the aromatics (Kennish, 1992; Dicks, 1999). Each type of oil has distinct physical and chemical properties. These properties affect the way oil will spread and break down, the hazard it may pose to aquatic and human life, and the likelihood that it will pose a threat to natural and man-made resources. The rate at which an oil spill spreads will determine its effect on the environment. Most oils tend to spread horizontally into a smooth and slippery surface, called a slick, on top of the water. Factors which affect the ability of an oil spill to spread include *surface tension*, *specific gravity*, and *viscosity*.

Already, in the first hours following oil spills the composition of the released oil changes significantly. A number of processes are responsible for this compositional change: spreading, weathering, evaporation, photochemical oxidation, dissolution, emulsification, sedimentation, adsorption and microbial degradation (Kennish, 1992; Kingston, 2002). After being released in the marine environment, it mostly takes at least a few hours to transport the oil into the coastal zone.

During this time interval, the aforementioned processes will strongly affect the composition and toxicity of the oil (Figure 1).

A number of analyses performed for the *Erika* accident by independent institutes identified the spilled oil as fuel # 2 (fuel # 6 or Bunker C, CAS No. 68553-00-4) (Boudet et al., 2000). In addition to paraffinic, cycloparaffinic and olefinic compound, fuel # 2 included a mixture of polycyclic aromatic compounds (PAC) which includes polycyclic aromatic hydrocarbons (PAH) and polycyclic heterocyclic hydrocarbons (PHH), such as carbazoles and thiophenes (Boudet et al., 2000; IARC, 1989). This is a type of the so-called "heavy fuel oils" which constitutes part of the "residual oils" classified as possibly carcinogenic to humans (Group 2B) by IARC (1989).

The effects and accumulation of total hydrocarbon concentrations in sediments and tissues after oil spills are often reported. However, the aromatic hydrocarbons are considered to be the components causing most observed biological effects after spills. These hydrocarbons, in fact, are most like to penetrate and disrupt cell membranes (Dicks, 1999). The greates toxic damage will therefore tend to be caused by spills of light oil (e.g. gasoline) or "fresh" crude. However, the most toxic components are also those that evaporate and disperse into the atmosphere most rapidly once the oil is relased and so any toxic effects on marine life to be highly localised and short lived (Dicks, 1999).

Spills of viscous heavy oils, such as some crudes and heavy fuel oil, may blanket areas of shore and kill organisms primarily through smothering (a physical effect) rather than through acute toxic effect. This is also the case with viscous water-in-oil emulsion ("mousse"). If thick layers of oil or mousse are not cleaned up they may incorporate sand, gravel and stones and harden into relatively persistent asphalt pavement (Dicks, 1999).

The relative amount of PAHs is highly variable depending on the particular crude oil. For example, Alaska North Slope (ANS) crude, the oil from the *Exxon Valdez* spill, has between 1.0 and 1.25% resolved PAH depending on its degree of weathering. As a general rule, there is more than one hydrocarbon source in an oil spill zone (e.g. Page et al., 1995). One difficulty with the analysis of subtidal hydrocarbon data is distinguishing oil spill hydrocarbons from other sources, both natural and anthropogenic. Background hydrocarbon concentrations can be quite high, particularly in petroleum producing regions (Lee & Page, 1997).

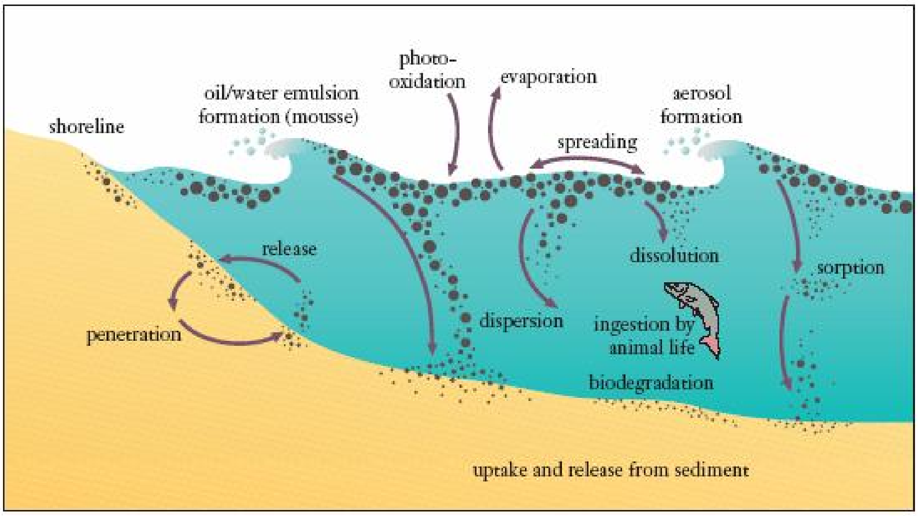

Figure 1: Processes following a spill (from IPIECA, 2000).

1.2 Oil spills sources and their identification

Worldwide accidents and wreckages of oil tankers are a cause of great public concern, especially because of the clear visual ecological impact of such incidents. However, these accidents are not the major causes of oil dispersal in the marine environment. Of all oil released in the marine environment about 33% is generated by the transport of oil; only one quarter of this quantity (8% of all oil) is caused by accidents and major spillages (Kennish, 1992). Despite the fact that oil tanker accidents are not the major contributors to oil released in the natural environment, they have raised a wide public concern by showing that oil pollution has profound effects on the sea and its inhabitants. For example, accidents of the *Amoco Cadiz* , the Exxon Valdez, the *Erika* and the recent wreckages of the *Prestige* and the Jessica have had great impact on the awareness of the hazards involved in oil transports (e.g. Lee and Page, 1997; Baars, 2002; Marshall and Edgar, 2003; Zenetos et al., 2004). Most of the hydrocarbon emissions from ships, in fact, results from routine operations such as loading, unloading and bunkering, and from illegal discharges of bilge waters, used oils and tank washing on the high seas. Though deliberate petroleum discharge from ships is banned in the Mediterranean and all 'operational' oily waste emissions are illegal, there is ample evidence for numerous, repeated, ongoing offences: analysis of satellite photos identified over 1,600 oil slicks in 1999 (Pavlakis et al., 2001) and 2350 oil slicks were observed in 2000 (EC, 2002) in the Mediterranean.

The environmental concerns and legal issues associated with accidental leakage or chronic release of crude oil and refined petroleum products to environment grow with each passing year (Wang et al., 1997).
Therefore, to unambiguously characterise, identify and quantify spill hydrocarbons is extremely important for environmental damage assessment, understanding their fate and behaviour and predicting the potential long-term impact of spilled oil on the environment by selecting appropriate spill response measures.
In addition, characterisation of chemical compositions and identification of oil spill sources are, in many cases, critical for settling disputes related to liability (Wang et al., 1999).
All crude oils and petroleum products, to some extent, have chemical compositions that differ from each other. This variability results in unique chemical "fingerprint" for each oil and provides a basis for identifying the source(s) of the spilled oils (Wang et al., 1999)
Besides, the fate and behaviour of spilled oil in the environment depend on the combination of several physicochemical and biological factors called "weathering". All these effects reduce the concentrations of hydrocarbons in sediment and water and alter the chemical composition of spilled oils. The changes in their chemical composition have strong effects on the toxicity and the biological impact of the oil over the time, and hence add great difficulties to the identification of the residual oil in the polluted environment.
A wide variety of instrumental and non-instrumental techniques are currently used in the analysis of oil hydrocarbons, which include gas chromatography (GC), gas chromatography-mass spectrometry (GC-MS), high-performance liquid chromatography (HPLC), sixe-exclusion HPLC, infrared spectroscopy (IR), supercritical fluid chromatography (SFC), thin-layer chromatography (TLC), ultraviolet (UV) and fluorescence spectroscopy, isotope ratio mass spectrometry and gravimetric methods. Of all these techniques, GC techniques are the most widely used (Wang et al., 1999).

Extraction of petroleum

The nature and size of releases due to petroleum extraction is highly variable, but it is restricted to areas where oil and gas exploration and development are under way. In the period 1985-2000, the number of offshore oil and gas platforms rose from a few thousand to about 8300 fixed or floating offshore platforms following the increase in world oil production (National Research Council, 2003). However, improved production technologies and safety training of personnel have dramatically reduced accidental spills from platforms to about 3% of petroleum inputs worldwide (Burgherr, 2007).

The largest accidental oil spill was a blowout at the Ixtoc-1 well that released 480 000 t of crude oil into the Gulf of Mexico over a 10-month period from June 1979 to February 1980 (Burgherr et al., 2004; Hirschberg et al., 1998).
Other famous accidents were the blowout of a well in the *Ekofisk* oil field, North Sea, that leaked 20,000 tonnes of oil in April 1977 and more recently (November 2004) an accidental release of crude oil, estimated at 157 barrels, from the Terra Nova FPSO (floating production, storage and offloading).

Refining and Consumption of petroleum

There are 82 main petroleum ports in the Mediterranean and just as many refineries, which process 8,780,326 barrels of crude oil a day, more than 10% of global refining. Italy is the nation with the highest number of refineries, which process a quarter of the crude oil compared to the entire Mediterranean Sea, with 14 main petroleum ports and 17 refineries. This data confirms the greater risk of sea pollution from hydrocarbons run by Italy, closely followed by France, with more than 1,900,000 barrels of oil processed a day, and Spain (1,321,500). However, it should be pointed out that outside the Mediterranean basin some countries have other main petroleum ports, namely 9 for Spain (Atlantic), 13 for France (Atlantic and the English Channel), 5 for Turkey (Black Sea) and 3 for Egypt (Red Sea) (AA.VV., 2007).
Recently, at the beginning of April 2007, about 22 tonnes of fuel oil (ATZ type with a high level of sulphur) spilled into the sea from the API oil refinery in Falconara (Italy)
Releases during the consumption of petroleum are as varied as its uses and main sources are rivers and runoff from land and operational discharges. Yet, these typically small but frequent and widespread releases constitute the majority of the petroleum that enters the sea due to human activity (Burgherr, 2007).
Below (Table 1) are listed the main petroleum ports and refineries in the Mediterranean.

Country	No. of Petroleum Ports*	No. of Refineries	Barrels/days processed	% processing on Med total
Italy	*14*	*17*	*2.300.800*	*26,2 %*
France	3	12	1,903,493	21,7 %
Spain	10	9	1,321,500	15,1 %
Egypt	2	9	726,250	8,2 %
Algeria	5	4	450,000	5,1 %
Greece	7	3	406,500	4,7 %
Libya	7	3	343,400	3,9 %
Croatia	5	3	260,337	3,0 %
Syria	3	2	239,865	2,7 %
Israel	3	2	220,000	2,5 %
Serbia Montenegro	1	2	158,250	1,8 %
Morocco	0	2	154,901	1,8 %
Turkey	9	6	100,000	1,1 %
Macedonia	0	1	56,730	0,7 %
Lebanon	3	2	37,500	0,4 %
Tunisia	6	1	34,000	0,4 %
Cyprus	0	1	27,000	0,3 %
Albania	1	2	26,300	0,3 %
Slovenia	2	1	13,500	0,1 %
Malta	1	0	-	-
Total	**82**	**82**	**8,780,326**	**100%**

Table 1: main petroleum ports and refineries in the Mediterranean (Bilaro e Mureddu, Unione Petrolifera , 2004 in AA.VV., 2007).

Acts of war

The main releases of oil caused by acts of war are:
1991- Kuwait- about 240 million gallons of oil were spilled from terminals, tankers and oil wells during the final phase of the invasion of Kuwait by Iraq.
1991- Persian Gulf- Iraq released about 460 million gallons (= 1,564,000 tonnes) of crude oil in the Persian Gulf during the Gulf War.
2006 - Lebanon - Israeli planes struck the Jiyyeh power plant, dumping 15,000 tons of heavy fuel oil into the eastern Mediterranean affecting most of the Lebanese coast while 55,000 tonnes burned.

CASE STUDY: Lebanon, 2006

On July 13 and 15, 2006 Israeli forces bombed Jiyyeh electric power plant, located along the coastline, 30 km South of Beirut, causing a major oil spill. It is estimated that 15,000 tonnes of heavy fuel spilled into the Mediterranean Sea, while a 55,000 tonnes burnt for more than three weeks releasing a smog of dioxins and noxious chemicals into the atmosphere.
South West to North East winds and water current pushed the oil spill northwards along the coast of Lebanon. The affected area spread through more than 100 km of rocky and sandy beaches, marinas, ports, fishermen harbours, and tourist resorts; extending from Jiyyeh south of Beirut all the way up to the Syrian boarders. The oil slick entered Syrian waters and has contaminated the coastline-north of the Lebanese-Syrian border so that the total area of contamination amounted at 140km in length and 15km in width. 80% of the heavy oil remains on and off the East Mediterranean shoreline, while around 20% has evaporated. The product spilled appeared to be an IFO 150 (Intermediate Fuel Oil with a viscosity of 150 cSt at 50°C).
The oil spill caused tremendous negative environmental, social and economical both on the short term and long term. It damaged marine ecosystems, destroyed fishermen's livelihoods and rendered coastal areas lifeless. The type of oil released, heavy fuel oil, is among the most difficult to combat: because of its viscous nature it has a prolonged persistence in the marine environment causing a widespread contamination. The marine ecosystem will thus take years to rehabilitate. The plume caused from the burnt fuel will increased cancer cases, respiratory problems and other diseases. The total economical cost of this oil spill has been estimated to be more than 200 million dollars.

Transportation of petroleum

At a world-wide level, petroleum is the good most transported by sea. About the 60% of petroleum used by dailing human activities (e.g. transports, heating, production of plastic materials,…) is usually transported by the sea. Eurostat (www.europa.eu.int/comm/eurostat) and Oecd/Iea (www.oecd.org; www.iea.org) estimated that in 1998 the transport of crude oil (75%) and its refined products (25%) amounted to about 2000 millions of tonnes. These vast amounts of crude oil and oil products transported annually by sea inevitably lead from time to time to accidental oil spills which have the most serious consequences on the world's coastlines. The main traffic roads are the ones from the producer countries (Middle-East and Persian Gulf) to Asia, Europe and United States, from northern Africa to Europe and from the Caribbean to the Unites States (Figure 2).
The petroleum traffic within the European Union represents the 27% of the world's traffics and the 90% of petroleum transportation is made by sea.
Since the opening of the Suez Canal in 1869, the Mediterranean regained its prominence as a hub of commercial shipping, and ever more so since the development of the Middle Eastern oil fields, and the ascendance of the Southeast Asian economies. It is estimated that about 220,000 vessels of more than 100 tonnes cross the Mediterranean annually, carrying 30% of the international seaborne trade volume, and 20% of the petroleum. With some 2000 merchant ships plying the Mediterranean at all times, accidental pollution as results of collisions or operational mishaps, and pollution stemming from the regular operation of ships, is significant (Galil, 2006).
Estimates in the 1970s placed the amount of oil that was spilled or discharged into the Mediterranean at between half a million and a million tonnes annually (Le Lourd 1977). Following ratification of the International Convention on Prevention of Pollution from Ships (MARPOL 73/78) and its more stringent protection measures for the Mediterranean Sea, plus the Convention for the Protection of the Mediterranean Sea against Pollution (Barcelona Convention) and its Protocols (see below), estimates were lowered in the 1990s to 600,000 tonnes. This is still an amount that marks the sea as one of the most oil-polluted regions in the world.

Petroleum transportation can result in releases of dramatically varying sizes, from major spills associated with tanker accidents to relatively small operational releases that occur regularly. Although tanker spills only account for about 15% of the annual total amount of oil entering the sea, they receive much attention for several reasons. Almost 60% of the oil consumed in the world is transported by tankers. Despite numerous efforts resulting in identifiable improvements, oil spills from tankers are still a major threat because many traffic routes cross the boundaries of the "Large Marine ecosystems" and of marine biodiversity hotspots (Roberts et al., 2002). The main releases due to transportation are related to pipeline spills and tanker vessel spills.

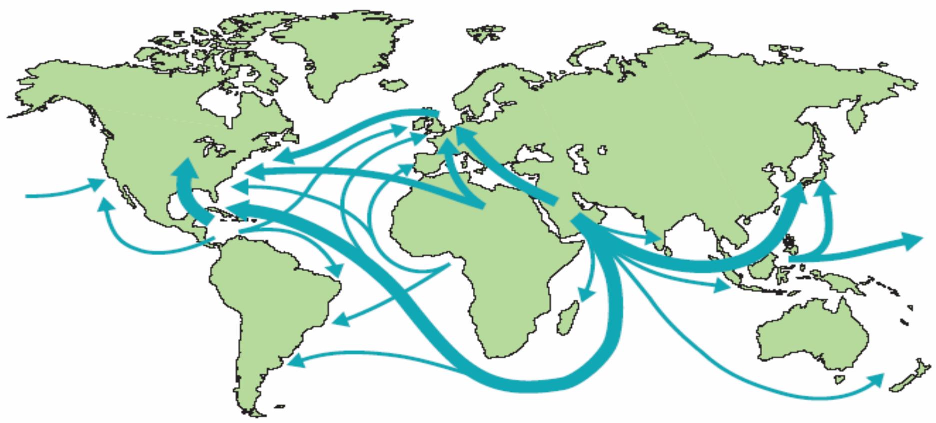

Figure 2: Pattern of major marine oil transportation.

Tanker spills

For what concerns Tanker spills, ITOPF distinguishes three spill size categories, namely <7, 7-700 and >700 t. 1970 was selected as the starting year for analysis of oil spill because it allowed an adequate representation of historical experience (Table 2).

Table 2: number of oil spill between 1970-2006 (ITOPF, 2007).

YEAR	7-700 Tonnes	>700 Tonnes
1970	6	29
1971	18	14
1972	48	27
1973	27	32
1974	89	28
1975	95	22
1976	67	26
1977	68	17
1978	58	23
1979	60	34
1980	52	13
1981	54	7
1982	45	4
1983	52	13
1984	25	8
1985	31	8
1986	27	7
1988	11	10
1989	32	13
1990	51	14
1991	19	7
1992	31	10
1993	31	11
1994	26	9
1995	20	3
1996	20	3
1997	28	10
1998	25	5
1999	19	6
2000	19	4
2001	16	3
2002	12	3
2003	15	4
2004	16	5
2005	21	3
2006	14	4

The incidence of “large” spills is relatively low and detailed statistical analysis is rarely possible, consequently emphasis is placed on identifying trends. It is evident that the number of large spills (>700 t) has decreased significantly during the last thirty years. The average number of large oil spills per year during the 1990s was less than a third of that witnessed during the 1970s. The vast majority of spills are “small” (i.e. less than 7 tonnes) and data on numbers and amounts is incomplete (ITOPF, Oil spill tanker statistics: 2006).

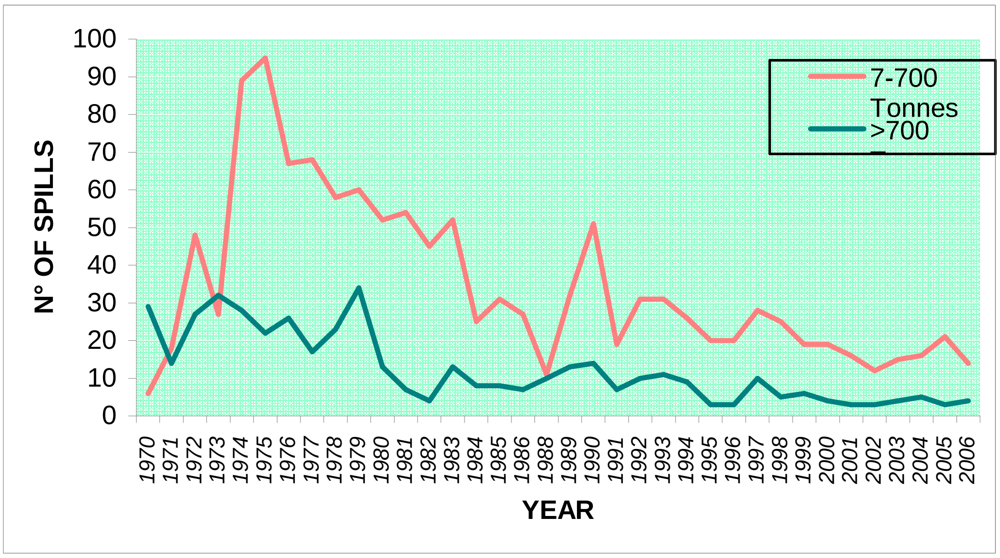

Figure 3: number of oil spills between 1970-2006 (modified from ITOPF, 2007).

Major Oil Spills

In Table 3 a list of the major oil spills with quantity of oil spilled and location is presented in order to have a panoramic view of the most affected areas worldwide and especially in Europe (European spills are written in light blue).

Table 3: Major Oil Spills since 1967 (Modified from ITOPF, 2007).

SHIPNAME	YEAR	LOCATION	SPILL SIZE
Atlantic Empress	1979	Off Tobago, West Indies	287,000
Fortuneship	1987	Iran	260,000
ABT Summer	1991	Off Angola	260,000
Castillo de Bellver	1983	South Africa	252,000
Amoco Cadiz	1978	Off Brittany, France	223,000
Son Bong	1985	Iran	200,000
Haven	1991	Genoa, Italy	144,000
Barcelona	1988	Iran	140,000
Odyssey	1988	Off Nova Scotia, Canada	132,000
Torrey Canyon	1967	Scilly Isles, UK	119,000
Sea Star	1972	Gulf of Oman	115,000
Texaco Denmark	1971	North Sea off Belgium	106,300
Urquiola	1976	La Coruna, Spain	100,000
Irenes Serenade	1980	Navarino Bay, Greece	100,000
M. Vatan	1985	Iran	100,000
Hawaiian Patriot	1977	Off Honolulu	95,000
Independenta	1979	Bosphorus, Turkey	95,000
Jacob Maersk	1975	Oporto, Portugal	88,000
Norman Atlantic	1987	Oman	85,000
Braer	1993	Shetlands, UK	85,000
Khark 5	1989	Off Atlantic coast of Morocco	80,000
Aegean Sea	1992	La Coruna, Spain	74,000
Sea Empress	1996	Milford Haven, Uk	72,000
Katina P.	1992	Mozambique	72,000
World Protector	1979	India	70,000
Nova	1985	Gulf of Iran	70,000
Wafra	1971	South Africa	63,000
Prestige	2002	Spanish coast, Galicia	63,000
Panoceanic Fama	1983	Iran	60,000
Neptunia	1985	Iran	60,000
Epic Colocotroni	1975	Porto Rico	57,000
Othello	1970	Sweden	55,000
Assimi	1983	Oman	54,000
Metula	1974	Strait of Magellan	53,000
Yuyo Marn	1974	Japan	50,000
Shinig Star	1987	Iran	50,000
Seawise Geant	1988	Iran	50,000
Andros Patria	1978	Spain	47,000
Pericles G C	1983	Qatar	46,000
British Ambassade	1975	North Pacific	45,000
Gino	1979	France	41,000
Corinthos	1975	Delaware, USA	40,000
Todotzu	1978	Strait of Hormuz	40,000
Burmah Agate	1979	Texas, USA	40,000
Napier	1973	Chile	38,000
Scapmount	1982	Iran	37,000
Exxon Valdez	1989	Alaska, USA	37,000
Erika	1999	France	31,000
Tasman Spirit	2003	Pakistan	27,000
Argo Merchant	1976	Massachussetts, USA	25,000
Nakhodka	1997	Japan	19,000
Nagasaki Spirit	1992	Indonesia	12,000

SHIPNAME	YEAR	LOCATION	SPILL SIZE
Sea Spirit	1990	Gibraltar	9,600
Al Samidoun	2004	Egypt, Suez	8,600
Tanio	1980	Brittany, France	6,000
Napoli	2007	Western Channel, north of Trégastel	3,000
Baltic Carrier	2001	Baltic Sea	2,700
Lyria	1991	France	2,200
Cercal	1994	Oporto, Portugal	2,000
Mega Borg	1990	Texas, USA	2,000
Tsesis	1977	Sweden	1,000
American Trader	1990	California, USA	1,000
Eurobulker	2001	Greece	700

In Figure 4 were reported the areas where occurred the main accidents of oil spill.

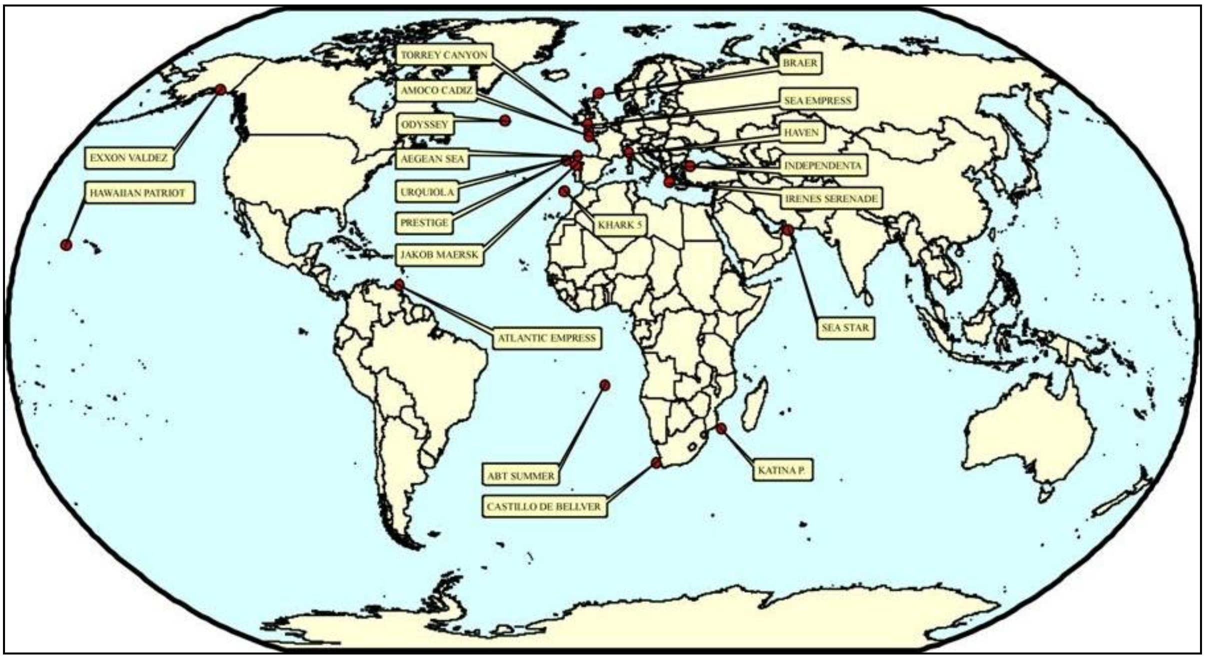

Figure 4: map of the major oil spills (ITOPF, 2007).

The highest spill frequency is underlined for Europe in the following areas:

- ✓ The Northern European Atlantic, particularly the coast of Galicia in Spain and the English Channel, and to a lesser extent for the North Sea,
- ✓ The Eastern Mediterranean.

NORTH EAST ATLANTIC

This region comprises countries that are major consumers of oil and consequently large volumes of both crude oil and refined products are transported within this area. A major proportion of crude oil is imported via the Mediterranean and Africa past the coast of Portugal, Spain and France. Whilst a proportion of this traffic supplies the domestic refineries of these three countries, laden tankers pass through the English Channel bound for the major oil refineries and terminals of Rotterdam, northern Germany and the Baltic countries. The tankers pass well off the French and Iberian coasts but do come close to land at Cape Finisterre, North West Spain and Ushant, France. Indeed there have been a number of major oil spills in these areas, mainly due to groundings.

Access to many of the oil terminals along the coast of Belgium, the Netherlands and Germany requires navigation of narrow rivers and channels: a large number of tankers transit these routes, creating a high risk of collision or grounding.

The North Sea is a major oil production area. While much of the output is carried in pipelines for domestic consumption, a high proportion is transported by shuttle tankers to terminals in Norway and UK. A significant portion is also exported to North America. This tanker traffic creates a risk of oil spills, notably in the shipping channels off northern Scotland.

Elsewhere, in the UK, the Solent area is an area of high risk with high volumes of shipping and a major refinery and terminal. Milford Haven is also a high risk area and has been the site of several major spills. A small refinery at Cork in southern Ireland generates some crude traffic to that country. This is supported by imports of refined products from the UK. Traffic traversing the Irish Sea generates a small risk of spills.

From different studies on the identification of the sources of pollution, it’s evident that rigs in UK waters make a significant contribution to all spills in its waters and also in Norwegian waters. The majority of spills in this region occur along the shipping routes from the Straits of Dover to the Baltic Sea. While the spills that occur in the northern part of the region (north of Scotland and western Norway) derive often by rigs operating in the offshore oil and gas industry (Carpenter, 2007).

In Table 4 were reported the main tanker spills of over 5000 tonnes occurred in the North East Atlantic region since 1974 (ITOPF, 2003) while in Figure 5 are reported the major oil spills in Brittany.

Table 4: Major tanker spills of over 5000 tonnes in the North East Atlantic region since 1974.

SHIPNAME	YEAR	COUNTRY	QUANTITY SPILLED		CAUSE
			Tonnes	Type	
Amoco Cadiz	1978	France	223,000	Crude	Grounding
Urquiola	1976	Spain	100,000	Crude	Grounding
Jacob Maersk	1975	Portugal	88,000	Crude	Grounding
Braer	1993	UK	84,000	Crude	Grounding
Prestige	2002	Spain	77,000	Fuel (Cargo)	Hull failure
Aegean Sea	1992	Spain	73,500	Crude	Grounding
Sea Empress	1996	UK	72,360	Crude	Grounding
Andros Patria	1978	Spain	50,000	Crude	Hull failure
Gino	1979	France	41,000	Carbon Black Feedstock	Collision
Betelgeuse	1979	Ireland	30,000	Crude	Fire/Explosion
Aragon	1989	Portugal	25,000	Crude	Hull failure
Erika	1999	France	19,800	Fuel (Cargo)	Hull failure
Tanio	1980	France	13,500	Fuel (Cargo)	Hull failure
New World	1994	Portugal	11,000	Crude	Collision
Bona Fulmar	1997	France	7,000	White product	Collision
Sivand	1983	UK	6,000	Crude	Collision
Böhlen	1976	France	5,700	Crude	Grounding
Eleni V	1978	UK	5,000	Fuel (Cargo)	Collision

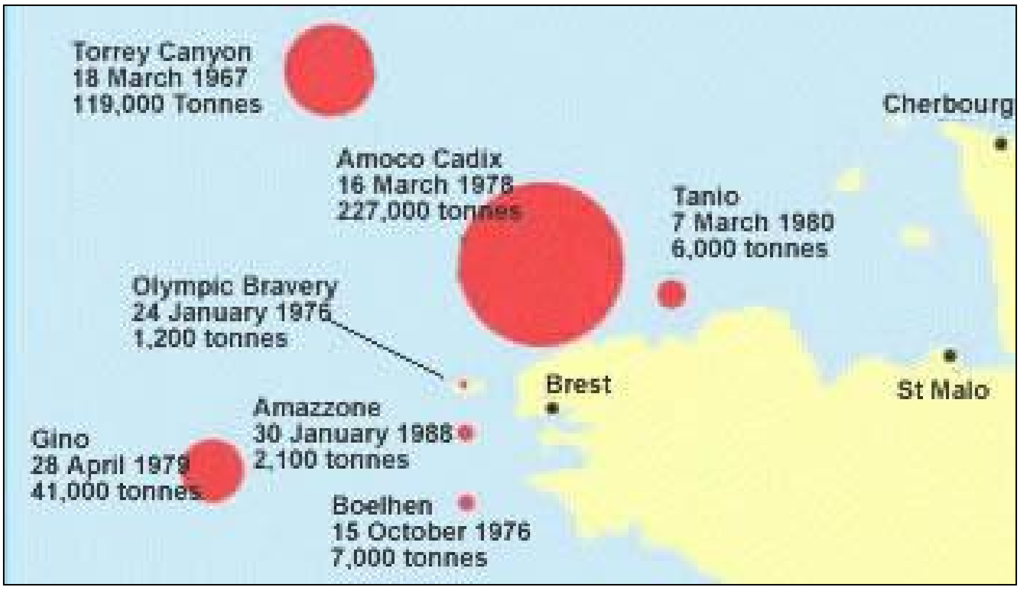

Figure 5: Major oil spills in the Brittany coast, France (www.cedre.fr).

Boxes below report brief descriptions of the main oil spills accidents occurred in the North East Atlantic Ocean.

CASE STUDY: *Amoco Cadiz,* France 1978

The tanker AMOCO CADIZ ran aground off the coast of Brittany on 16 March 1978 caused by a steering gear failure. During the following two weeks the tanker released its entire cargo of 223,000 tonnes of light Iranian and Arabian crude oil and 4,000 tonnes of bunker fuel into heavy seas (Hess, 1978). Much of the oil quickly formed a viscous water-in-oil emulsion, increasing the volume of pollutant by up to five times. By the end of April, oil and emulsion had contaminated 320 km of the Brittany coastline and had extended as far east as the Channel Islands (Bern6 & D'Ozouville, 1979).
A wide variety of shore types were affected, including sandy beaches, cobble and shingle shores, rocks, seawalls and jetties, mudflats and saltmarshes: rocky shores recovered relatively quickly while the salt marshes took many years.
The at-sea response did little to reduce shoreline oiling because of strong winds and heavy seas and problems with seaweed and debris mixed with the oil.
A considerable portion of the oil that did come ashore eventually became buried in sediments and entrapped in the low energy salt marshes and estuaries.
Cleanup activities on rocky shores, such as pressure-washing, as well as trampling and sediment removal on salt marshes caused biological impacts. Failure to remove oil from temporary oil collection pits on some soft sediment shorelines before inundation by the incoming tide also resulted in longer-term contamination
At the time, the AMOCO CADIZ incident caused the worst loss of marine life ever recorded after an oil spill. Two weeks after the accident, millions of dead molluscs, sea urchins and other benthic species washed ashore. 20,000 dead birds were recovered, most of them were diving birds. Luckily many species had recovered within a year. Oyster cultivation in the estuaries ("Abers") was seriously affected as well as other fin fisheries and tourism.

This catastrophic black tide has not been a unique case: in 1967 the Torrey Canyon ran aground in front of the English coasts of Cornawall affected the littoral of Brittany. Just one year after the Amoco Cadiz oil spill the tanker Gino sank off Ouessant and in 1980 the tanker Tanio broke into two during a storm off the coast of Brittany.

Special issue of Marine Pollution Bulletin, 9(11), 1978.

CASE STUDY: *Sea Empress*, UK 1996

The oil tanker *Sea Empress* ran aground off St. Ann's Head at the mouth of Milford Haven, south west Wales on February 15, 1996. Approximately 72,000 tonnes of light crude oil (Forties Blend) and 480 tonnes of heavy fuel oil were released into the surrounding waters, resulting in the contamination of 200 km of the Pembrokeshire coastline, while visual evidence indicated that appreciable amounts of oil were washed up the Haven as far as Pembroke (SEEEC, 1998). The area contaminated is well known for its natural beauty and is utilised for a variety of purposes such as tourism, fisheries and aquaculture. With the relatively sheltered deep water providing a suitable harbour for large vessels Milford Haven was developed as a major oil terminal. The Milford Haven waterway has been subject to inputs of hydrocarbons originating from the petroleum industries flanking its shores since the 1960s. Other inputs originate from domestic sources and road run-off as well as from an oil-fired power station. However, Little et al. (1987) estimated that no more than 240 tonnes of oil entered the Haven annually, most of it well dispersed in water, and already associated with suspended particles. Consequently, it is not unusual to find relatively high levels of hydrocarbons in the sediments of the Haven. However, the patterns observed in the distribution of total hydrocarbons (THC) before and after the 'Sea Empress' foundered would indicate appreciable contamination of the Haven occurring as a result of the disaster.

The Environmental Impact of the Sea Empress Oil Spill. 1998. SEEEC Sea Empress Environmental Evaluation Committee. Published by The Stationery Office.

CASE STUDY: *Erika*, France 1999

On 12 December 1999, the tanker *Erika* wrecked in two parts at about 60 km from the Brittany French coasts (Point of Penmarc'h, Sud Finistère, France). About 10,000-15,000 tonnes of fuel were released in the marine environment. A number of analyses performed by independent institutes identified the spilled oil as fuel # 2 (fuel # 6 or Bunker C, CAS No. 68553-00-4) (Boudet et al., 2000). The transported oil was lowly volatile, had a poor solubility and a low dispersal potential (for a specific analysis of the Erika oil see IFP, 2003). In the weeks/months following the accident, the oil was washed ashore along a 400 km stretch of the French coastline.

Special Issue (July-September 2004): The "*Erika*" Oil Spill: Environmental Contamination and Effects in the Bay of Biscay. Aquatic Living Resources, 17(3).

CASE STUDY: *Prestige*, Spain 2002

On Wednesday 13 November 2002, the tanker *Prestige* (81,564 DWT), carrying a cargo of 77,000 tonnes of heavy fuel oil, suffered hull damage in heavy seas off northern Spain. She developed a severe list and drifted towards the coast, and was eventually taken in tow by salvage tugs into the Atlantic. She broke in two early on 19 November some 170 miles west of Vigo, and the two sections sank some hours later in water two miles deep. In all, it is estimated that some 63,000 tonnes were lost from the *Prestig*e.

Owing to its highly persistent nature the released oil drifted with winds and currents, travelling great distances. Oil first came ashore in Galicia, where the predominantly rocky coastline was heavily contaminated, then it moved into the Bay of Biscay affecting the north coast of Spain and the Atlantic coast of France, as far north as Brittany. Some light and intermittent contamination was also experienced on the French and English coasts of the English Channel. Although oil entered Portuguese waters, there was no contamination of the coastline.

The response, which was probably the largest international effort of its kind ever mounted, was hampered by severe weather and by the inability of those vessels that lacked cargo heating capability to discharge recovered oil.

Almost 50,000 tonnes of oil-water mixture were removed in the open-sea and over 20km of boom were developed but they failed to prevent extensive coastal contamination: approximately 1,900 km of shoreline were affected. A further problem was re-oiling of previously cleaned areas by re-mobilised oil. In total, some 141,000 tonnes of oily waste was collected in Spain and 18,300 tonnes in France.

Fisheries exclusion zones were put in place in Galicia shortly after the incident, banning virtually all fishing along about 90% of the coastline until October 2003. The impact on fisheries in France was less extensive. In both countries, an impact on tourism was reported for 2003.

The Spanish authorities decided to remove the oil remaining in the wreck. The work commenced in May 2004 and was finalised in September 2004 at an estimated cost of some €100 million.

The Prestige oil spill caused the third black tide occurred along Galician coasts, after the *Urquiola* (1976) and the *Aegean Sea* (1992). Moreover it was the third black tide within European waters in less than 4 years: before there were the *Erika* (1999) and the Baltic Carrier (2001).

www.otvm.uvigo.es/vertimar2007.
Special issue of Marine Pollution Bulletin, 53(5-7), 2006.

CASE STUDY: *Napoli,* western Channel 2007

On 18 January 2007, the British container ship the Napoli, en route from Antwerp to Lisbon, was caught in a storm at the entry to the Channel and suffered a leak and a failure of her steering system. She was transporting 2,394 containers, carrying nearly 42,000 tonnes of merchandise, of which some 1,700 tonnes were classed as hazardous substances (explosives, flammable gases, liquids and solids, oxidants, toxic substances, corrosive materials...). In her bunkers, she held 3,000 tonnes of heavy fuel oil.

The 26 crew members were evacuated from the vessel by 3 British Sea King helicopters. The French Préfecture Maritime de l'Atlantique conducted a risk assessment before carrying out a towing attempt on the abandoned ship. Cedre participated in this assessment for certain common aspects involved in accidents at sea: drift predictions of the movements of the wreck, containers which may fall into the sea and oil slicks in the event of a spill. However, an additional exceptional element was also to be assessed in this emergency situation: analysis as of 4 pm of the risks of pollution posed by products in the cargo classed as hazardous, making use of a 106-page list containing up to 7 entries per page.

Two types of dangers were examined and discussed by the committee of experts at the Préfecture Maritime: the risks for responders (explosive or flammable substances and toxic gases) and the risks for the marine environment (aquatic pollutants, toxic substances for the flora and fauna). The problem in this type of situation is not so much the dangers caused by a product in isolation, which we can find information about in specialised literature, but rather the problem, as demonstrated by the cointainer ship MSC Rosa M, of interference between products, such as a product which is flammable when in contact with water being close to a heat reactive substance. The problem is also managing to react quickly without neglecting any aspect. Furthermore, the danger caused by a product or contact between products is not only a question of composition, but also depends on packaging. The same product packaged in metal barrels which will withstand several weeks in seawater, in sealed plastic bags which will float on the surface or in cardboard boxes which will disintegrate in the water, should not be considered in the same way. A substance which is denser than water in packaging with good buoyancy should not be considered in the same way as the same product in bulk in a container which will sink quickly. Unfortunately, packaging lists often use vague terminology such as "box" or "package", which do not allow their water resistance to be determined. Despite these elements of incertitude, the risk analysis was carried out in this case in six hours, by a team put together by our intervention department. The comittee of experts was able to withdraw at midnight, having given a detailed opinion to the operational services of the Préfecture Maritime.

The risk of the vessel breaking during towing could not be excluded. After inspection, the assessment team gave clearance for the *Napoli* to be towed by the Abeille Bourbon, in order to control her drifting, whilst waiting for a decision on where the vessel was to be taken. This decision was made on the 19th jointly by the French and British authorities. The destination chosen was the port of Portland, on the coast of Dorset. Over the following hours, the convoy moved out of the French zone of responsibility and management of the affair was taken over by the Maritime and Coastguard Agency. Whilst en route, due to the growing risk of the vessel breaking, the convoy was diverted to Lyme Bay, where the *Napoli* was beached. This practice of beaching vessels is not exceptional and was carried out very successfully in the case of the cointainer ship Rosa M.

On 26^{th} of January packets of chocolate biscuits arrived, covered in fuel oil, on the French coastline between Finistère and the Côtes d'Armor. *Napoli* fuel oil was analysed in order to compare it with the samples collected on Brittany shoreline.

During one week, local municipalities from Finistère and Côtes d'Armor, helped by a unit of the Civil Safety were involved in the clean up of sandy beaches and rocky areas polluted by accumulations of oiled biscuits packets and patches of fuel oil.

MEDITERRANEAN

Since the opening of the Suez Canal in 1869, the Mediterranean regained its prominence as a hub of commercial shipping, and ever more so since the development of the Middle Eastern oil fields, and the ascendance of the Southeast Asian economies. It is estimated that about 220,000 vessels of more than 100 tonnes cross the Mediterranean annually, carrying 30% of the international seaborne trade volume, and 20% of the petroleum. With some 2000 merchant ships plying the Mediterranean at all times, accidental pollution as results of collisions or operational mishaps, and pollution stemming from the regular operation of ships, is significant (Galil, 2006). Estimates in the 1970s placed the amount of oil that was spilled or discharged into the Mediterranean at between half a million and a million tonnes annually (Le Lourd 1977). Following ratification of the International Convention on Prevention of Pollution from Ships (MARPOL 73/78) and its more stringent protection measures for the Mediterranean Sea, plus the Convention for the Protection of the Mediterranean Sea against Pollution (Barcelona Convention) and its Protocols (see below), estimates were lowered in the 1990s to 600,000 tonnes. This is still an amount that marks the sea as one of the most oil-polluted regions in the world.
The high level of hydrocarbon transportation in the Mediterranean probably constitutes the most serious danger for the survival of this sea, which unsurprisingly has the highest hydrocarbon density in the world. Data provided by UNEP MAP estimates that **100-150,000 tons of oil end up in the Mediterranean Sea every year**. An impressive quantity which is unfortunately confirmed by the density of pelagic tar found in its waters, with an average of 38 milligrams per cubic metre; the highest in the world. Just compare it with the 3.8 of the Japanese seas, 2.2 of the Gulf Stream or 0.8 of the Gulf of Mexico to understand the risk the Mediterranean is experiencing (AA.VV., 2007).
The transportation of petroleum products within the Mediterranean basin represents more than 20% of the world traffic of petroleum products and it amounts to 360 millions of tonnes per year:

- 300 millions enter the Mediterranean and are directed to countries belonging to the basin: especially crude oil from Eastern countries to Italy, and from northern Africa to France and refined products from France to Algeria;
- 20 millions leave the Mediterranean: especially refined products through Suez and Gibraltar;
- 40 millions cross the basin from East to West and North to South;
- about 250-300 tankers cross the Mediterranean everyday.

Even if accidental oil spills are not among the chief contributors to the deteriorating state of the Mediterranean Sea, they represent a continued risk of acute pollution.

Besides petroleum and its refined products transportation, all the activities that are generally associated with oil pollution risk can be found in the Mediterranean. These include exploration and production of oil and gas, movement of oil from offshore wells to shore (by ships or sub-sea pipelines), as well as large-scale commercial and passenger shipping.
Offshore oil and gas reserves are located along the Adriatic coast of Italy, in the Greek Aegean Sea, the Lion Gulf and the Strait of Messina, though the most important areas are the Gulf of Gabes off Tunisia and the contiguous shelf off Libya.
The largest exporters of crude oil in the Mediterranean are Libya, Algeria, Egypt, and Syria. The region's major importers of crude oil are France, Italy, Spain and Turkey.
The major shipping axis runs from east to west, from the Middle East (about 150 MT going through the Suez Canal and the Sumed pipeline), passing between Sicily and Malta and following closely the coasts of Tunisia, Algeria and Morocco. Traffic on that axis attenuates as it moves westwards and branches off towards unloading terminals near Piraeus, Greece, the northern Adriatic, the Gulf of Genoa and near Marseilles; it is intersected by tanker routes connecting the Algerian and Libyan loading terminals (about 100 MT) with the northern Mediterranean oil ports. The second important route (only partially used in the past decade due to the Iraqi embargo and the post war disruptions in Iraqi oil production) connects crude oil terminals in the Gulf of Iskenderun and on the Syrian coast with Gibraltar and the northern

Mediterranean ports. A third route, from the Black Sea through the Istanbul Straits (about 70 MT) leads westwards to join the main axis. Satellite images of the Mediterranean taken in 1999 reveal oil spill concentrations along those routes, in the vicinity of the Egyptian coast, the Adriatic, the straits of Sicily, the Ligurian Sea and the Gulf of Lion covering an area of 17,141km² (Pavlakis et al. 2001).
Trade in refined and residual products shows a more complex structure. A number of refineries, particularly along the European coasts of the Mediterranean supply the many local ports, but also more distant European ports outside the Mediterranean. Refined products are also shipped into the region from refineries in other parts of Europe. Of course, the shores of all countries located along the major shipping routes, not only those importing or exporting large volumes of oil or refined products, are exposed to risk due to passing tankers. Oil transport to and through the Mediterranean is expected to rise with the full lifting of economic sanctions from Libya, and completion of pipelines from the Caspian Sea oil fields: Baku-Ceyhan (capacity 1 million bbl/d, by 2005), Baku-Supsa (115,000 bbl/d in 2001, proposed upgrade to 600,000 bbl/d), Baku-Novorossiisk (50,000 bbl/d in 2001, 100,000 bbl/d capacity), Baku-Novorossiisk (Chechnya bypass) (120,000 bbl/d current, 360,000bbl/d, by 2005), Kazakhstan- Novorossiisk (400,000 bbl/d in 2002, 565,000 bbl/d capacity, 1.34 million bbl/d, by 2015), and several 'Bosphorus Bypass' pipelines planned with termini at Omisalj (Croatia), Trieste (Italy) and Alexandropoulis (Greece) (EIA, 2004). The implementation of the new "motorways of the sea" component of the EU "Trans-European Transport Network" initiative, set for 2010, will increase further the volume of maritime traffic in the Mediterranean Sea (Galil, 2006). Key risk areas for collisions in the Mediterranean are the waters of the Dardanelles in the Turkish Straits, the Strait of Messina and the narrow Strait of Gibraltar: All these locations have a large vessel traffic volume and have experienced tanker accidents in the past. However, the greatest frequency of these accidents occurred in and around major ports such as the ones in southern Greece, northern Italy (Genoa, 1991) and southern France (ITOPF, 2003).
Of the 268 accidents listed by the Regional Marine Pollution Emergency Response Centre for the Mediterranean (REMPEC) for the 1977-1995 period, more than three-quarters involved oil. As a result of shipping accidents an estimated 22,223 tonnes of oil were spilled into the sea between 1987 and 1996. A review of the causes attributed to all large tanker spills (>700 tonnes) in the Mediterranean since 1960s underlines the most frequent risks involved in oil tanker operations such as grounding (38%), collision (27%), equipment or hull failure (18%) and fire (12%). Since 1985 there have been **27 accidents** in the Mediterranean (ITOPF, 2003) considering only the main ones, leaving out another thirty of more modest size, with a **total spill of more than 270,000 tons of hydrocarbons**. Italy holds the record of crude oil spills in the main accidents, with 162,600 tons, followed by Turkey, with almost 50,000 tons and Lebanon, with 29,000. The worst accident the Mediterranean ever witnessed was the terrible catastrophe of the Haven in 1991, when the waters surrounding Genoa in Italy were contaminated with 134,000 tons of hydrocarbons.
In the **Table 5** are listed the major accidental oil spills in the Mediterranean since 1970 (ITOPF, 2003). The **HAVEN** and **IRENES SERENADE** incidents rank among the ten largest spills recorded world-wide.
The number of reported accidents is rising, with 94 events reported in 2000-2003, 24 of which resulted in oil spills (

Table 6) (REMPEC, 2004).

Table 5: Major tanker spills of over 5000 tonnes in the Mediterranean since 1970.

SHIPNAME	YEAR	COUNTRY	QUANTITY SPILLED		CAUSE
			Tonnes	Type	
Haven	1991	Italy	140,000	Crude	Fire/Explosion
Irenes Serenade	1980	Greece	~ 100,000	Crude	Fire/Explosion
Tanker Maltese		Turkey	45,700		
Trader	1972	Greece	37,000	Crude	Hull failure
Ellen Conway	1976	Algeria	32,000	Crude	Grounding
Juan Antonio Lavalleja	1980	Algeria	30,000	Condensate	Grounding
AGIP Abruzzo	1991	Italy	23,000	Fuel	Collision
Theodoros V	1974	Italy	22,000	Crude	Equip. failure
Cavo Cambanos	1981	Spain	20,000	White Product	
Al Dammam	1977	Greece	16,000	Crude	Unknown
Marlena	1970	Italy	15,000	Crude	Grounding
Sea Spirit	1990	Gibraltar	10,000	Fuel (Cargo)	Collision
Al Rawdatain	1977	Italy	8,300	Crude	Equip. failure
Southern Cross		Algeria	8,000		
Geroi Chernomorya	1992	Greece	8,000	Crude	Collision
Chenki		Egypt	7,800		
Bello	1972	Italy	6,500	Crude	Fire/Explosion
Texanita	1972	Libya	5,700	White Product	Collision
Olympic Sun	1971	Tunisia	5,500	Fuel (Cargo)	Grounding
Messiniaki Frontis	1979	Greece	5,000	Crude	Grounding
Petrogen One		Spain	5,000		
Vera Berlingieri	1979	Italy	5,000	White Product	Collision

Table 6: Accidental Oil Spills in the Mediterranean 2000-2003 (Source of Data: REMPEC, 2004).

Date	Location	Spilled	Remarks
21/02/2000	Vatika bay, Neapolis Voion, Greece	Bunkers	The ship sank with 20T of diesel and 5 barrels of lube oil on board. Leakage of bunkers and oily mixtures reported.
9/03/2000	Salamis Island, Greece	Bunkers	Slight leakage of gas oil reported after the grounding
15/06/2000	Kynosoura, Salamis Island, Greece	Oily waste	Black iridescent oil slick spotted by A.HCG. Surveillance aircraft after the explosion of the "Slops" which is used as a storage and treatment vessel for oil residues.
29/08/2000	Kithira Island, Greece	Fuel oil	The ship had 250T of fuel oil, 25T of gas oil and 7T of lubricating oil on board, part of which was spilled and polluted the shoreline.
1/9/2000	Khalkis Port, Greece	Bunkers	The ship broke in two during loading cement and eventually sank. She had 670T of fuel oil, 25T of diesel oil and 775L of lube on board. Serious shoreline pollution reported.
8/9/2000	Porto Vesme, Italy	Bunkers	Following grounding, a leak of bunker oil was reported. She had a total of 170T of fuel oil and 35T of diesel oil on board.
1/10/2000	Psara Island, Greece	Other oily wastes	After grounding a small spill noted around the ship by HCG surveillance aircraft. The ship had 289T of fuel oil, 38T of gas oil and 167T of fuel sludge.
10/11/2000	Pachi, Megara, Greece	Crude oil unspecified	A leak from the vessel at Greek petroleum new quay
24/11/2000	Eleusis Bay, Greece	Other oily wastes	The vessel, which was laid up, developed a sudden list and sank. Small pollution reported.
23/1/2001	South of Fontvielle, Monaco	Bunkers	The source of pollution reported unknown.
27/3/2001	Near Tripoli, Lebanon	Bunkers	An oil spill of unknown origin and described as fuel oil was spotted near Tripoli, covering "few kilometres".
5/5/2001	Southwest of Tsoungria Island, Greece	Bunkers	The ship grounded with 239T of fuel oil and 24T of diesel on board. A private contractor appointed to undertake response operations. 3 tag boats, 3 patrol boats and an antipollution vessel.
12/6/2001	Agioi Theodoroi, Greece	Oily waste	Minor pollution caused when gasket on hose coupling burst during loading of lube oil base by the tanker (according to: Hazardous Cargo Bulletin).
18/6/2001	West of Kavo Maleas, Greece	Fuel oil, diesel oil	The tanker grounded under "unidentified conditions" and after cargo transfer operation was completed on 22-06, refloated and towed towards Piraeus for repairs.
11/1/2002	Thessaloniki, Greece	Bunkers	The incident occurred during bunkering of passenger/ro-Ro Express Appolon.
4/8/2002	Algeciras, Spain	Bunkers	Small quantity of oil (150L) spilled during bunkering of the salvage tug.
7/9/2002	Thessaloniki, Greece	Bunkers	Pollution was caused by a leak from the terminal's underwater pipeline during discharge operations.
21/12/2002	Algeciras, Spain	Bunkers	The vessel which spilled fuel oil during refueling operation.
3/1/2003	Karystos, Greece	Bilges	Slick 30 N/miles long and 10m wide.
7/1/2003	Ancona, Italy	Bunkers	Slick pushed back out to the sea by winds.
29/1/2003	Off Tipaza, West of Algiers, Algeria	Bunkers	Cougar sank quickly under the weight and uneven distribution of its cargo of red potters clay.
5/3/2003	Kalymnos, Greece	Bunkers	Oil slick successfully dispersed by Matsas Star.
11/7/2003	Eleusis Port, Greece	Bunkers	Medoil III sustained 1.5m fracture above waterline causing 200 m2 diesel oil pollution.
22/10/2003	Agioi Theodoroi, Greece	Crude oil	Incident due to a disconnected discharging arm.

Besides these accidents, other minor spills occurred in the Mediterranean waters during the last years are:

2000 - Greece:

- The tanker Eurobulker sank in Southern Evoikos Gulf spilling 700 tonnes of crude oil.

2007 - Italy:

- The tanker Chem Star Eagle has lost 9 tonnes of fuel oil from a hull failure off Livorno due to bad weather.

CASE STUDY: *Haven,* Italy 1991

On the 11th April 1991, the Mediterranean suffered from the worst and biggest oil spill accident ever occurred in the region. The Very Large Crude Carrier "*Haven*", built in 1973 with a carrying capacity of more than 250,000 of crude oil, was anchored in front of the port of Genoa, ITALY, when two violent explosions started a fire that lasted for 70 hours until the tanker sunk. The ship was carrying 144,000 tons of "heavy Iranian crude oil": most of oil burnt and sank as bitumen while the rest was dispersed by the Ligurian-Provencal current and by the winds affecting both Italian and French coasts.

In order to prevent pollution the oil at sea was let burning and ship was tug coastward but it broke into two parts: the bow part with two tanks lies at 490 m depth and main part is at 75 m depth.

Just immediately after the sinking several safety procedure were undertaken and accompanied by monitoring programs for the evaluation of chemical pollution.

Thirteen years later, as some oil was occasionally spilling from the main wreck and the sea bottom was still covered by several tar deposits decontamination was needed, mainly in order to prevent the risk of leakage of oil and hydrocarbons due to material corrosion and the collapse of the ship structure.

Causes of spills from tankers

The release of oil is usually due to a combination of factors including weather conditions and human errors. Other key factors involved in oil spills are the *hull type* (Pre-MARPOL single hull and MARPOL single hull tankers), the *tanker age* and *accident causes* dominated by dramatic events such as collisions, groundings and explosions/fires.
Most spills from tankers come from routine operations such as loading/discharging and bunkering in ports or at oil terminals and the quantity of oil spilled in these cases is relatively small (the 91% are less than 7 tonnes).
Larger spills are usually the results of accidents such as collisions and groundings and the 84% releases more than 700 tonnes of oil.
More precisely the single causes (Figure 6) amount at:

- 34% for loading and discharging operations;
- 7% for bunkering;
- 13% for other operations;
- 2% collisions and 3% groundings;
- 8% hull failures;
- 1,5% for fire and explosions;
- 25% for other causes or unknown.

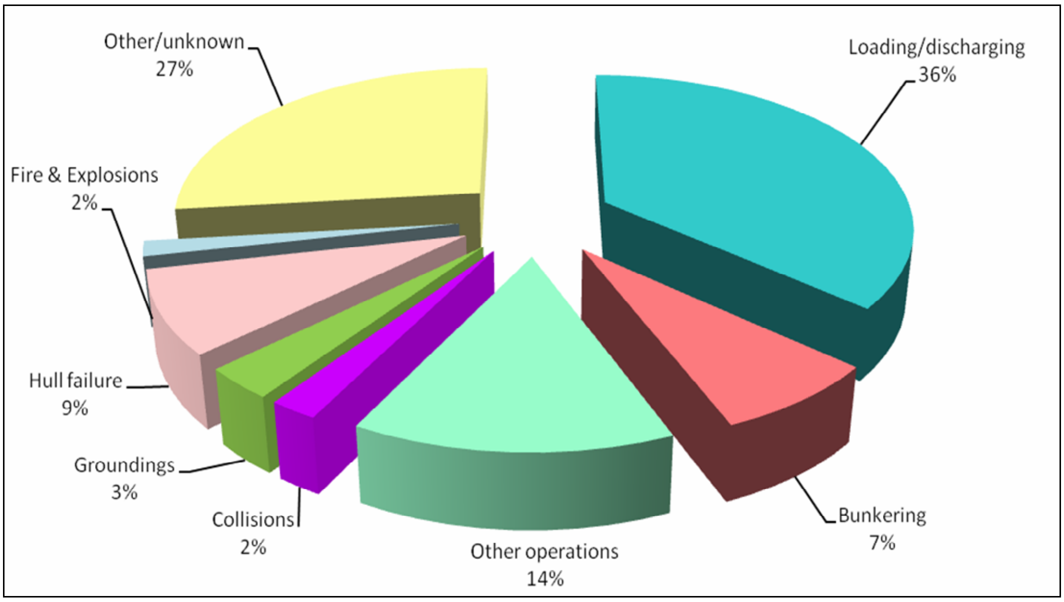

Figure 6: causes of spills from tankers.

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Web-sites

- ✓ **www.cedre.fr** – CEntre for Documentation, Research and Experimentations on Accidental Water Pollution (CEDRE) created in 1978, in the aftermath of the *Amoco Cadiz* oil spill, in a bid to be more fully prepared for accidental water pollution and to strengthen the national response organisation.
- ✓ **www.epa.gov** – Environmental Protection Agency, (USA).
- ✓ **http://ec.europa.eu** – European Commission.
- ✓ **http://greenline.org.lb/new/english/index.html** - Green Line (Lebanon), non-governmental association involved with principles of environmentally sound development in the developing world.
- ✓ **www.haven.it** – Web-site dedicated to the Haven Oil Spill occurred in April 1991 in front of Genoa, Italy
- ✓ **http://www.ieo.es/prestige/resultados.htm**
- ✓ **www.imo.org** - International Maritime Organization (IMO)
- ✓ **www.iopcfund.org** - International Oil Pollution Compensation Funds (IOPC Funds)
- ✓ **www.ipieca.org** - International Petroleum Industry Environmental Conservation Association (IPIECA)
- ✓ **www.itopf.com** - International Tanker Owners Pollution Federation Limited (ITOPF)
- ✓ **www.legambiente.com** – LEGAMBIENTE (Italy), ONLUS Environmental Association (in Italian)
- ✓ **www.maree-noires.com** – Pedagogical dossier about Black Tides (in French)
- ✓ **www.maib.gov.uk** – Marine Accident Investigation Branch
- ✓ **www.mcga.gov.uk** – Maritime and Coastguard Agency (U.K.) and the Coastguard Agency's Marine Pollution Control Unit (MPCU) formed in 1967 following the *Torrey Canyon* incident.
- ✓ **www.noaa.gov** – National Oceanic & Atmospheric Administration (U.S. Department of Commerce)
- ✓ **http://response.restoration.noaa.gov** – NOAA's Office of Response and Restoration
- ✓ **www. oceanography.ucy.ac.cy**
- ✓ **www.oilspilllebanon.org** – Web-site dedicated to the Oil Spill occurred in Lebanon in 2006 caused by acts of war
- ✓ **www.ospar.org** - Convention for the Protection of the Marine Environment of the North-East Atlantic (the "OSPAR Convention")
- ✓ **www.otvm.uvigo.es** - Technical Bureau of Marine Spills (OTVM - Spain), responsible for management and coordination works that Scientific Coordination Commission determines.
- ✓ **www.rempec.org**

1.3 Government and Scientific Coordination developed during oil spill emergencies

The **European Community** has played a vital role in the field of response to marine pollution since the Council Resolution of 26 June 1978, which set up "**an action programme of the European Communities on the control and reduction of pollution caused by hydrocarbons released at sea**".
At present, the role of the European Community in the field of response to marine pollution finds its legal basis in Decision n° 2850 of 20/12/2000 of the European Parliament and the Council setting up a Community framework for cooperation in the field of accidental or deliberate marine pollution. This framework has been established for the period 1 January 2000 to 31 December 2006, and its aim is to:

- support and supplement Member States' efforts;
- contribute to improving the capabilities of the Member States for response in case of incidents;
- strengthen the conditions for and facilitate efficient mutual assistance and cooperation;
- promote cooperation among Member States in order to provide for compensation for damage in accordance with the polluter-pays principle.

The European Commission - Environment Directorate-General/Civil Protection Unit - with the help of a Management Committee on Marine Pollution implements the framework for cooperation via:

- A Community Information System with the purpose of exchanging data on the preparedness for and response to marine pollution.
- A three-year rolling plan which includes actions such as training, exchange of experts, exercises, pilot projects, surveys of the environmental impact after an accident, etc.

Community Action in response to marine pollution emergencies was further reinforced after the Council Decision of 23 October 2001 established a Community Mechanism to facilitate reinforced cooperation in civil protection assistance interventions.
In December 2006 the European Commission issued a communication (2006/0863) presenting the current state of Community action in terms of preparedness and response to marine pollution, and indicating how the Commission, despite the expiry of the Community framework at the end of 2006, intends to continue and promote its activities to the full in this field from 2007, in an appropriate framework.
In the aftermath of the *Erika* disaster, the European Union decided to strengthen its role in the field of maritime safety and pollution by ships with the Regulation (EC) N° 1406/2002 of the European Parliament and of the Council of 27 June 2002 establishing the **European Maritime Safety Agency** (EMSA). The goal of the Agency is to provide technical and scientific assistance to the European Commission and Member States on matters relating to the proper implementation of European Union legislation on maritime safety and pollution by ships. In addition to its initial safety and pollution related work, in March 2004, EMSA was also given additional tasks related to oil pollution response.
The Community is also actively participating in international cooperation activities.
The European Community plays a central role between Member States as a contracting party to all major regional conventions and agreements covering regional seas around Europe, such as the Helsinki Convention 1992 for the protection of the Baltic Sea, the Bonn Agreement 1983 for the protection of the North Sea, the Barcelona Convention 1976 for the protection of the Mediterranean Sea and the (yet to be ratified) Lisbon Agreement for the protection of the North-East Atlantic

The creation of **National or International Scientific Committees** is of primary importance to achieve a better coordination. The committee should be composed by politician and scientists with a previous knowledge or training on oil spills. They should work for:

- Coordination of the preparative works;
- Involvement in operational committee (integrated in the decision process);
- Management of the oil spill pollution (recommendations, guidelines, coordination, valorisation).

Also, when definig an impact assessment response framework, it is necessary to take into account:

- procedures recognized by scientists at national and international level before a spill occurs;
- methods fitted for the pollution (size, type, location,…) and for the different aims of the EIA than can be (proving the impact, determining the loss, assessing recovery, discussing for cleaning or not, or for stopping cleaning operations, building a compensation file, etc…)

Besides, the creation of National and/or International Scientific Committees after an oil spill it must be underlined the **instituition of specific Agencies and Centres** to provide a prompt response and a scientific coordination.

- **European Maritime Safety Agency** (EMSA)
- **Coastguard Agency**'s Marine Pollution Control Unit (MPCU): formed in 1967 following the *Torrey Canyon* incident, to provide a command and control structure for decision making and response following a shipping incident that causes, or threatens to cause, pollution in UK waters (www.mcga.gov.uk; www.oceanography.ucy.ac.cy);
- **Cedre** (Centre of Documentation, Research and Experimentation on Accidental Water Pollution): created in 1978, in the aftermath of the *Amoco Cadiz* oil spill, in a bid to be more fully prepared for accidental water pollution and to strengthen the national response organisation. It is responsible, on a national scale, for documentation, research and experimentation on pollutants, their effects and the response means and tools that can be used to combat them. Its expertise encompasses both marine and inland waters. It is financed both by subsidies and by public and private contracts (www.cedre.fr);
- **US National Response Team:** an interagency group co-chaired by the EPA and the U.S. Coast Guard, providing technical assistance, resources and coordination on preparedness, planning, response and recovery activities for emergencies involving hazardous substances, pollutants and contaminants, hazmat, oil, and weapons of mass destruction in natural and technological disasters and other environmental incidents of national significance.
- **RRIT** (Réseau de Recherche et d'Innovation Technologiques) a Network of Research and Technological Innovation on the theme of "Accidental Marine Pollution Events and their Ecological Consequences": created after the oil spill following the sinking of the *Erika* (1999) by the Comité Interministériel de l'Aménagement et du Développement du Territoire (**CIADT**) in order to take a series of measures to cope with the consequences, to improve the measures for the prevention of such accidents, and to reinforce the means available to combat them (http://www.ritmer.org);
- **SEEEC** *Sea Empress* Environmental Evaluation Committee, an independent committee set up on 27 March 1996 by the UK Government
- **Scientific Coordination Commission** and **Technical Bureau against Accidental Marine Spills**: created in 2002, after the *Prestige* oil spill;
- **Strategic Action against Marine Oil Spills** funded by the Spanish Ministry of Education and Science. A total of 97 research projects were approved.
- **IMO's** Marine Environment Protection Committee developed the International Convention on Oil Pollution Preparedness, Response and Cooperation, 1990 (the OPRC Convention) to provide a framework for international cooperation for combating major oil pollution incidents (www.imo.org).

Moreover, several specific and sectorial scientific **Projects** are often funded by the European Community and/or National Governments. For example, can be citated (since, 2004):

- **Properties of Russian oils and the applicability of dispersants** (Analysis of Russian oil). The objective of the project is to analyse both Russian crude and bunker oils. - funded by the EC, 2006
- Response means to chemicals spilled at sea and environmental damage (Response to chemical spills - **RESPIL**). The project will propose a panel of well-established biological- and ecotoxicological methodologies for their use in the assesment of environmental damage and recovery following chemical pollution.- funded by the EC, 2006

- **Super CEPCO** The first objective is to perform a continuous monitoring of ship-source marine pollution by oil or other harmful substances which can be traced at the sea surface. The second objective is to evaluate the use of satellites for marine pollution monitoring and surveillance. The third objective is to maximize the chance of catching MARPOL offenders red-handed while discharging oil or other harmful substances in the sea and finally, the results of the operation and the outcome of the evaluation workshop will enable the project team to draft European Guidelines on oil pollution monitoring, detection and reporting procedures for use at national and at sub-regional level - funded by the EC, 2006
- **A pragmatic and integrated approach for the evaluation of environmental impact of oil and chemicals spilled at sea: input to European guidelines** The project will address issues that relate to the evaluation of the long lasting environmental impact of spill related to aging processes of substances from past accidents along the EU coastal zone. The project aims at implementing well-established methodologies based on biological marker measurements as decision-making criteria for the assessment of environmental impact of oil and chemical spill at sea and integrate them in existing EU guidelines. It also aims at proposing simple, cost-effective analytical tools based on biosensors as monitoring techniques- funded by the EC, 2005
- **Analyses of survey, modelling and remote sensing techniques for Monitoring and Assessment of environmental impacts of submerged oil during oil spill incidents**. The projecte dealt with the identification and quantification of patches of submerged oil- funded by the EC, 2005
- **Development of European Guidelines for potentially polluting wrecks**. The final products will be a database, implemented with a Geographic Information System (GIS), able to provide the relevant information on the matter and to classify the shipwrecks on the basis of the environmental risk they potentially pose.- funded by the EC, 2004
- **Response to harmful substances spilled at sea** project act to monitor the flow of chemicals, to describe a risk analysis methodology for chemicals and to identify the behaviour and effects of relevant types of chemicals in the marine environment- funded by the EC, 2004
- **Relative impact of starvation and oil on digestive and kidney functions of sea birds,** project with the aim to improve the criteria of triage of the oiled birds- funded by the EC, 2004
- **ESEOO**: Establishment of an Operational Oceanography System in Spain.
- **ECOPREST**: Evaluacion del impacto de los vertidos del *Prestige* sobre el ecosistema de la plataforma y sus recursos pesqueros.
- **IMPRESION**: IMpacto del vertido de hidrocarburos del PREStige sobre la red trofica microbiana planctONica.
- **Urgent, Special Actions**,
- **VEM-2004** projects
- **Complementary Actions** 2004

More in detail, below are reported the examples of the government management and its deciosions applied for the *Prestige, Amoco-Cadiz*, and Lebanon oil spills.

In Spain, immediately after the ***Prestige*** oil Spill in 2002 that affected the Galician coasts as an answer to the social and scientific demand for undertaking the assessment and monitoring of damages, the Spanish government approved the **Scientific Intervention Programme** with clear aims for research. To carry out this Programme, which needed interdisciplinary and interinstitutional collaboration, a **Scientific Coordination Commission** was appointed to supervise the Urgent Special Actions for the monitoring, assessment and management of the first actions undertaken immediately after the *Prestige* oil spill. Around 170 researchers belonging to 29 different institutions have taken part in these projects: the tasks finished at the end of 2003 and the conclusions were published in the Volume 53 (Issues 5-7) of the *Marine Pollution Bulletin* in 2006.
Then the Scientific Coordination Commission was committed with monitoring the VEM-2003 and VEM-2004 research **projects** under the **Strategic Action against Marine Oil Spills** funded by the Spanish Ministry of Education and Science. A total of 97 research projects were approved and they lasted for a period of three years involving about 650 researchers from 36 different institutions.

In order to monitor research projects related to *Prestige* 's oil spill, especially projects funded by the Strategic Action against Marine Oil Spills undertaken by the Spanish Ministry of Education and Science (Urgent, Special Actions, VEM-2003 projects, VEM-2004 projects and Complementary Actions 2004), VERTIMAR-2007 Symposium took place in Vigo (Galicia, Spain) between 5th and 8th June 2007. Together with previous VERTIMAR-2005 Symposium, its aim was to constitute a forum where researchers from different fields can meet, present, discuss and transfer their projects' results easily. Around 130 researchers from 50 different institutions attended the Symposium and presented their research work in 67 oral communications and 69 posters.
Besides, the week before the Symposium (May 28th -June 1st, 2007), two practical-theoretical workshops were held in the University of Vigo: "Methodology for studying fuel buried in the beaches" directed by Ana Bernabeu (Univ. Vigo) and "Oceanographic modelling and oil spill drift" directed by Carlos Souto (Univ. Vigo).

In 1997 CEDRE, founded after the ***Amoco Cadiz*** oil spill, organised a Survey with French Experts to assess a feedback about the environmental impact assessment of the *Amoco Cadiz* oil spill (1978). Scientists were asked for suggestions based on their previous and direct experience on marine oil spills in order to give an idea of the main recommendations needed to achieve a prompt decision. Their answers underlined the primary importance of:

- improving the knowledge on re-settlement and recovery processes;
- setting up of reference in order to create baseline databases with pre-spill time series as well as control sites during the spill;
- facilitating, implementing multi-disciplinary approaches;
- using pre-defined methods and procedures to have standardised data useful for statistical analysis and comparisons.

More recently the International aid asked by the **Lebanon** authorities highlighted the increasing need of collaborations between national and international experts in oil spill, and of prompty recovering actions in order to develop an action plan and to limit the damages.
In July 2006, the Republic of Lebanon's Ministry of Environment requested assistance through the REMPEC regional Mediterranean response centre from the members of the Barcelona Convention and other partners of the Mediterranean Action Plan and, also, addressed a request for experts and material to the European Commission, which communicated this request to the member States. In August, the Lebanese Minister of the Environment sends to the Italian Ministry of the Environment a formal request for an intervention in Lebanon to support the clean-up activities following the Israeli bombing at Jieh power plant. By the 5th August, the pollution had spread to the Syrian shores, and Syria in turn requested assistance from REMPEC. In September the Italian Ministry of the Environment positively replies to the formal request and sends some experts (APAT/ARPA-ICRAM) for a preliminary survey.
In particular, the chronology of the Italian mission can be summarised as follows:

• 24.08.2006: the Lebanese Minister of the Environment sends to the Italian Ministry of the Environment a formal request for an intervention in Lebanon to support the clean-up activities following the Israeli bombing at Jieh power plant;
• 07.09.06: the Italian Ministry of the Environment positively replies to the for the formal request and sends some experts for a preliminary survey;
• 19.09.2006: the Lebanese Ministry of the Environment extends its request by asking for an aerial surveillance (remote sensing) by the Italian Coast Guard, that arrived in Larnaka Cyprus on the 27th September;
• 20.09.2006: the ITCG “Peluso” arrives in the Beirut port;
• 21.09.2006: the ITCG “Peluso” and Coast Guard Divers starts operations in Jieh;
• 27.09.2006: the S/V “Tito” arrives to Jieh port;
• 28.09.2006: Castalia starts operations with S/V Tito;
• 14.10.2006: assessment of the area completed and 40 tons of pollutant recovered;
• 04. 11.2006: S/V Tito leaves to Italy for turn around;
• 09.11.2006: ICRAM/ARPA dive with “Bahar Lubnan” for area survey;
• 10.11.2006: ICRAM/ARPA dive with “Bahar Lubnan” for area survey;
• 11.11.2006: ICRAM/ARPA dive with Coast Guard for area survey;

• 14.11.2006: up to date “Bahar Lubnan”, with the indications given by ICRAM/ARP dives has recovered ten more cubic meters of pollutant.

In the framework of the Italian environmental intervention in Lebanon, the main objective of the participation of the Italian Environmental Agency Network was to provide technical-scientific co-ordination and direction in order to guarantee sound scientific basis and environmental sustainability to the investigation and clean-up activities.
Upon request from REMPEC, Cedre provided information on the different techniques suitable for pollution response on the shoreline and played the role of general secretary for an international experts working group in charge of establishing a response plan. During the second week of August, pollution response specialists were sent to assess the situation in Lebanon (European Commission) and in Syria (REMPEC). REMPEC also called upon CYCOFOS (the Cyprus Coastal Ocean Forecasting and Observing System) for information on pollutant behaviour and drift predictions. Like the MOTHY model activated by Météo France at Cedre's request, these predictions indicated a tendency for the pollution to drift northwards, progressively polluting the shoreline. Several satellite images, handled by CYCOFOS and the Joint Research Centre of the European Commission, confirmed this northward movement of the pollution. The work carried out by the Experts Working Group acted as a basis for establishing an international assistance action plan which was validated on 17th August in Piraeus (Greece) at a coordination meeting between the contributor organisations and the representatives of the countries in the area. This **Action Plan** was made up of three phases:
- a short term phase, gathering in an organised manner the contributions of equipment and emergency specialists to combat the pollution;
- a medium term phase, once the clean-up plan was organised, gathering the contributions and financial aid within a structured shoreline clean-up programme;
- a long term phase, including a detailed impact study and reinforcement measures for the national and regional major pollution response capacities.

2 Literature Research on the main impacts of oil spills on coastal environment

2.1 Effects of oil spills on the coastal environment

The environmental impact of oil spills has been extensively researched over the past 30 years and a considerable amount has been learnt about the nature and duration of such effects. As a result, our predictive capability is probably better for oil spills than for many other types of marine pollutant.
The range of biological impacts after an oil spill can encompass:

- Physical smothering effects on flora and fauna;
- Lethal or sub-lethal effects on flora and fauna:
- Physical and chemical alteration of natural habitits, e.g. resulting from oil incorporation into sediments;
- Changes in biological communities resulting from oil effects on key organisms, e.g. increased abundance of intertidal algae following death of limpets wich normally graze the algae.

Aquatic environments are made up of complex interrelations between plant and animal species and their physical environment. Harm to the physical environment will often lead to harm for one or more species in a food chain, which may lead to damage for other species further up the chain. Where an organism spends most of its time—in open water, near coastal areas, or on the shoreline—will determine the effects an oil spill is likely to have on that organism.
Petroleum and its derivates in marine environment go under different transformations on the base of the type of oil. The oil which has evaporated is photooxidated producing CO_2, CO and other organic compounds with oxygen. Photoxidation involves the surface layer of oil too.
The oil that reaches the bottom is the most dangerous as it can be up taken by the benthic organisms while the most refractory fraction can remain unaltered for years, but if the environmental conditions change or sediments are disturbed it may enter again the ecosystem (Azoulay et al., 1979, 1983a).

<u>Factors that determine seriousness of impact</u>

The impact of oil spills on marine ecosystems and subsequent recovery rates are the result of different factors: amount of oil spilled (the thickness of deposit on the shore and on the sea surface, the sediment deposition,…), type of oil (see above), the causes and the way the accident occurred, local geography, distance from coast, weather conditions, season, the biological and physical characteristics of the area, relative sensitivity of species and biological communities,... The effects of a spill, in fact, may vary markedly between winter and summer. Winter oiling of a saltmarsh, for example, may have little effect on the above-ground parts of plants as many naturally die-back at that time of year. However, oil can affect over-wintering seeds and reduce germination in the spring. In spring or summer oil can damage new growth and may cause marked reduction of flowering if plants are oiled when the flower buds are developing. Even though there may be good vegetative recovery, there is loss of seed production for that year (Dicks, 1999). According to season, also, vulnerable groups of bird or mammals may be congregated (perhaps with young ones) at breeding colonies and fish and shellfish may be spawing in shallow nearshore waters. Winter months may see large groups of migratory waders and sea ducks feeding in estuaries and coastal areas. At such times the effects of a spill can be considerably increased (Dicks, 1999).

Usually, a significant spill can produce both acute effects on short term and chronic effects on long term especially on eggs and larvae of fishes, on crustacean in particular the zooplankton, on filtering invertebrates and the sea birds that come into contact with the oil layer at the surface of the sea. Besides, when the black tide reaches the coast it also affects the sessile organisms.
For what concerns the acute effects the most evident is the tiny oily film that appears on the surface that:

- Blocks the air exchange at the surface creating anoxic conditions;

- Reduces the penetration of light needed by phytoplankton and seagrass with the result of a lower primary production;
- It adheres to the organisms that live at the interface between air and water stopping their vital functions.

Chronic effects are related to sub-lethal concentrations of oil and hydrocarbons: they don't provoke death but they succeed in affecting the chemical and physical conditions of the environment with rebounds on the whole community such as:

- Changes in organisms' physiology and behaviour;
- Changes in species composition;
- Changes in ecological interactions for example along the trophic chain.

After an oil spill, the objectives of monitoring studies are usually: (i) to identify the short-term effects of the hydrocarbons (categories of organism affected by the spill, and estimation of mortalities; i.e. the "resistance" of the community) and (ii) to evaluate the time required for decontamination of the sediment and organisms, and for recovery of pre-spill population levels (i.e. the "resilience" of the community) (Gomez Gesteira et al., 2003). In several cases, the time required for recovery of pre-spill population levels has 10 years (see Dauvin, 1998 and Gomez Gesteira, 2001, for reviews). In contrast, some communities, such as the fine-sand *Abra alba* community of the Bay of Morlaix, have shown very high resiliences: 15 years after the *Amoco Cadiz* spill the *Ampelisca* populations, which initially disappeared, showed complete recovery. In such surveys, several authors have recommended the identification of organisms to species-level, in view of the information offered by such an approach (species richness, species appearance and disappearance, comparative investigations at the mesoscale, etc.).

2.1.1 Effects of oil spills on the Ecology and Biodiversity

The occurrence of several major oil spills and the chronic pollution of the oceans in recent decades have resulted in extensive research on the fates and effects of hydrocarbons in marine environments.

Most of the scientific literature focuses on the effects of oil spills on marine organisms (e.g. plankton, sessile or benthic organisms, fishes, marine mammals,…). Several studies have shown the impact of oil pollution on various benthic organisms, such as bivalves, gastropods, foraminifera, copepods, nematodes and sea urchins (e.g. Stegeman and Teat, 1973; Shaw et al., 1976; den Hartog and Jacobs, 1980; Vénec-Peyré 1981; Alongi et al., 1983; Majeed 1985; Yawetz et al., 1992; Yanko et al., 1994; Alve, 1995; Temara et al., 1999; Bernhard et al., 2001; Hamoutene et al., 2002; Lee et al., 2002; Le Hir and Hily, 2002; Le Cadre, 2003; Suderman and Thistle, 2003; Morvan et al., 2004; Martinéz-Jerónimo et al., 2005). Benthic communities, in fact, are sensitive to oil spills, but the effects of oil pollution strongly depend on the proportion of hydrocarbon-sensitive species, especially crustaceans, in the affected community (see Dauvin, 1998, 2000).

Many studies, often, show both the immediate effects caused by the spills on the environment and its inhabitants and the long term effects, by an activity of monitoring after the oil spill, in order to study the recovering capacity of different communities. It was shown that the perturbations were more pronounced in fine sediment communities (Dauvin and Gentil, 1990). Studies reported as the level of impact shown at the community level can vary considerably. Several studies found that the level of impact of spill was related to the amount and characteristics of oil incorporated into sediments (Grassle et al., 1981; Glémarec and Hussenot, 1981). Where sediment hydrocarbon concentrations did not exceed 50 mg kg^{-1} benthic communities remained unmodified. However, at concentrations greater than 100 mg kg^{-1} opportunist polychaetes dominated and in sediments containing 1% oil opportunists thrived to the exclusion of all other taxa.

No mass mortalities were recorded in areas off the Shetland Islands where over 85,000 t of oil were spilt from the *Braer* and sediment concentrations exceeded 3500 mg kg^{-1} (Kingston et al., 1995; Feder and Blanchard, 1998) noted little evidence of long term impacts on the benthos of Prince William Sound following the grounding of the *Exxon Valdez*. Similar results were reported after smaller spills in the Baltic Sea (Lindén et al., 1979; Bonsdorff, 1981; Elmgren et al., 1983). However, an increase in diversity was reported in communities impacted by oil from the *Amoco*

Cadiz with an increase in polychaete numbers in the three years following the spill (Dauvin, 1982) and dramatically increased recruitment of the bivalve *Macoma balthica* was observed following the *Tsesis* spill in the Baltic sea (Elmgren et al., 1983).

Whereas the level of impact associated with oil contamination indicated by whole community data may be somewhat variable and unpredictable, trends in the populations of particular species can be more useful. The use of indicator species is widespread with several models built around the concept of pollution tolerant and intolerant animals (e.g. Leppäkoski, 1975; Pearson and Rosenberg, 1978) and those which flourish or decline in the presence of oil have been identified. Some species, such as *Ampelisca* spp. and other amphipods, can be considered as good indicators of oil pollution; by contrast, polychaetes appear to be resistant to high levels of hydrocarbons in sediment (Gomez Gesteira and Dauvin, 2000). These authors proposed the use a polychaetes/amphipods ratio to reflect changes in the soft-bottom macrobenthos, analogous to the nematodes/copepods ratio previously suggested for the meiobenthos. The polychaetes/amphipods ratio requires only family-level identification of polychaetes, since the characteristic opportunistic polychaete response to increased organic matter is generally detectable as family level increases in the abundance of Capitellidae, Cirratulidae, Spionidae and/or Eunicidae (Gomez Gesteira and Dauvin, 2000). However, the ratio may be considered only as a general indicator of oil pollution, with supplementary investigations required for a more precise assessment of the impact and amelioration of oil pollution (Nikitik and Robinson, 2003). The Capitellidae, especially *Capitella* spp., are well known opportunist animals which were found in extremely high numbers following the *Florida* spill in North America (Sanders et al., 1980), while it was present in small numbers in Milford Haven throughout the study period (Nikitik and Robinson, 2003). Kingston et al. (1995) concluded that moderate populations of *Capitella* spp. indicated some evidence of impact associated with the *Braer* spill. However, numbers in the Haven were much lower than those recorded off the Shetland Isles and as such animals are likely to be present in small numbers in undisturbed environments, only becoming dominant in suitable conditions, their presence cannot be associated with *Sea Empress* oil. Proliferation of members of the polychaete family Cirratulidae has also been observed in oil contaminated sediments and in the middle and lower Haven in 1997 (Conan, 1982; Dauvin, 1982; Kingston et al., 1995; Nikitik and Robinson, 2003). These increases are likely to be related to the *Sea Empress* despite the eighteen month time lag, as similarly delayed responses were reported from other oil spills (Kingston et al., 1995; Gómez Gesteira and Dauvin, 2000).

The general intolerance of the Amphipoda to pollution has been reported by Bellan-Santini (1980) in a long-term study on the French Mediterranean coast, and this group has been shown to be particularly sensitive to oil pollution. Massive mortalities of amphipods were recorded in the aftermath of the grounding of the *Amoco Cadiz* (Cabioch et al., 1978; den Hartog and Jacobs, 1980) following the foundering of the *Tsesis* (Lindén et al., 1979; Elmgren et al., 1983) the *Antonio Gramsci* (Bonsdorff, 1981) and the *Braer* (Kingston et al., 1995). For example, in the fine sand community at Pierre Noire station in the Bay of Morlaix, where the amphipods *Ampelisca* spp. were the dominant species before the spill, reductions of about 20% in species numbers, 80% in density and 40% in biomass occurred immediately after the stress (Dauvin, 1979).

Amphipods have been shown to select clean rather than oil contaminated sediments (Percy, 1977) and Lindén et al. (1979) considered emigration as a possible cause for the decline in amphipod numbers in the area of the Baltic affected by the *Tsesis* spill, although Elmgren et al. (1983) believed such a mass migration to be unlikely. Migration also seems implausible for the decline in numbers in Milford Haven as any such movements up the Haven would have resulted in either an increase in numbers in the upper reaches, or seaward migration of animals from the upper Haven into more heavily contaminated areas further downstream. Impoverished populations of amphipods were found in sediments containing low levels of oil from the *Braer* which Kingston et al. (1995) related to short term exposure of the benthos to high concentrations of oil without hydrocarbons being incorporated into the sediment due to the lack of fine material. Similar processes are likely to be occurring in Milford Haven where coarse sediments predominate. Recovery of the amphipod fauna was evident in all reaches of Milford Haven by 1998, a pattern which generally continued in 2000, although abundances were still lower in the middle reaches compared to pre-spill records (Nikitik and Robinson, 2003). A recovery of the amphipod fauna was also reported by Elmgren et al. (1983) in the second summer after the *Tsesis* spill and recolonisation of the Brittany coast has been observed following the *Amoco Cadiz* spill. However, numbers of *Ampelisca* spp. took fifteen

years to regain pre-spill levels on parts of the Brittany coast due to their total disappearance following the spill and relative remoteness from other breeding populations (Dauvin, 1998).
Other taxa need to be identified as suitable indicators, such the amphipod groups *Harpinia* spp. and the Isaeidae (Nikitik and Robinson, 2003). However, these are not ubiquitous taxa and it is probable that suitable indicators will have to be selected on a case by case basis.
Other scientists focused their attention on the microbial studies, dealt with hydrocarbon degradation or the effect of oil on aerobic microorganisms and processes (Azoulay et al., 1979, 1983 a,b). Colwell & Walker (1977) have generalised that oil spills inhibit certain naturally occurring groups of bacteria and result in increased numbers of oildegrading bacteria. Several studies have examined the effects of oil on microorganisms in marine and estuarine sediments (Walker et al., 1975; Knowles & Wishart, 1977; Griffiths et al. 1981; Winfrey & Ward, 1981; Winfrey et al., 1982)
Together with different programmes of ecological monitoring focalised to evaluate the impact and the evolution of polluted sites based on infaunal structure analysis in time and space, further investigations were carried out in the sediment to estimate the organic matter content (organic carbon and nitrogen) and its role on the fauna alteration. Majeed (1987) carried out a study on the organic carbon and nitrogen analysis in the sediment, with the application of a biotic index. Results showed a different classification of the fine sand beaches in three categories separating the perturbated, unbalanced and the normal stations. Also, C:N ratios in spite of their relative precision appeared to be around 6-7 for the normal stations but >15 for the unbalanced and heavily perturbated stations.
Other stidues dealt were focused on the effects by oil contamination on the plants communities. PAH uptake from soil by vegetation may depend on PAH concentration (Anderson et al., 1997). They are most likely to be accumulated in the roots and not be translocated to shoots because of their high hydrophobicity, as reflected by high octanol-water partitioning coefficient (logKow). Its toxicity to plants could be due to water repellency caused by hydrocarbon residues. Certain flowering plants, marine algae and bacteria have evolved a number of adaptations to different types of environmental stresses. Some of these adaptations are metabolic and others are structural (Rathinasabapathi, 2000). However, the biochemical mechanisms of adaptation of some plants to oil pollution are poorly investigated and the signaling pathways involved remain elusive (Hussein and Terry, 2002).
Scientific attention is also focused on the effects of oil pollution on seabirds. Important and detailed studies were carried out, for example, after the *Erika* oil spill (eg. Cadiou and Dehorter, 2003; Cadiou et al., 2003a,b, 2004; Bretagnolle et al., 2004; Castège et. al, 2004; Kammerer et al., 2004). The *Erika* oil spill, in fact, has been a major ecological disaster for seabirds, unique in the history of oil spills for several reasons (Bretagnolle et al., 2004). First, the ship sank (on 12 December 1999) nearly 100 km offshore, and freed c. 20 000 tons of fuel which drifted at sea for 15 days. Second, the hurricane *Lothar* that occurred on 28-29 December precipitated the oil spill on the coast, which covered nearly 500 km of the French Atlantic coast. Finally, this oil spill killed more seabirds than any before in Europe: nearly 70 000 guillemots (*Uria aalge*) were found dead or alive on beaches (Cadiou et al., 2004). For comparison, the *Exxon-Valdez* oil spill killed c. 35 000 birds, though the estimated total of dead birds was 250 000-300 000 (Piatt et al., 1990; Ford et al., 1996). From the *Erika* oil spill the project, "*ERIKA-Avion*", was approved to provide the first distribution maps of seabirds wintering in the entire Bay of Biscay and abundance estimates for major species.
The environmental impact assessment gives, also, a great attention on the effects of oil spill on fishes (Brannon et al., 2006) and marine mammals (Gaskin, 1994). After the Exxon Valdez oil spill, various research were designed to study the effect of oil exposure on the heme biosynthesis, in particular of the river otters, *Lontra canadensis* (Taylor et al., 2000) and Steller sea lions, *Eumetopias jubatus* (Beckmen et al., 2002). In such a situation, high levels of porphyrins were found in erythropoïetic tissues, kidney and liver as well as in faeces, secretions and excretion products (Casini et al., 2003).
Marine pollution monitoring programs are increasingly including the assessment of the biological effects of pollutants by means of biomarkers (Den Besten, 1998; Cajaraville et al., 2000; Lam and Gray, 2003). Concretely, the OSPAR Convention, that includes Galicia and Bay of Biscay in its "Joint Assessment and Monitoring Program (JAMP)", incorporates the use of biomarkers (Stagg, 1998; OSPAR Commission, 2000). Biomarkers, considered as "early warning signals", may be useful to promptly detect biological effects after oil spills and to somehow predict long-term changes. Biomarkers are measurements at cellular, biochemical and molecular levels that indicate

the presence of pollutants (exposure biomarkers) or the magnitude of the biological response to pollutant exposure (effect biomarkers; McCarthy and Shugart, 1990). Changes at simple levels of biological complexity (molecule, cell, tissue) can anticipate changes at more complex levels such as population, community or ecosystem (Cajaraville et al., 1993). In order to achieve environmentally significant conclusions, biomarkers must be applied as a battery of measurements, including both exposure and effect biomarkers (Cajaraville et al., 2000). Mussels are the most widely used sentinel organisms in pollution monitoring programs aimed to study the health of coastal and estuarine environments (Goldberg, 1975; Stagg, 1998; UNEP/RAMOGE, 1999; Cajaraville et al., 2000; Nasci et al., 2002; Monirith et al., 2003), the Mussel Watch (Goldberg, 1975) being the oldest biomonitoring program in progress worldwide (Monirith et al., 2003). Mussels tolerate exposure to xenobiotics and respond in a broad range of ways that can be measured as biological effect biomarkers.

Biomarkers have been often used in sentinel mussels and fishes after accidental oil spills. In order to assess the biological effects of the *Prestige* oil spill, mussels (*Mytilus galloprovincialis*), European hake (*Merluccius merluccius*) and European anchovy (*Engraulis encrasicolus*) were sampled. In mussels, several cell and tissue biomarkers were measured: peroxisome proliferation as induction of acyl-CoA oxidase (AOX) activity, lysosomal responses as changes in the structure (lysosomal volume density, V_{VL} , surface-to-volume ratio, S/V_L, and numerical density, N_{VL}) and in membrane stability (labilization period, LP), cell type replacement as relative proportion of basophilic cells (volume density of basophilic cells, VV BAS) in digestive gland epithelium, and changes in the morphology of digestive alveoli as mean luminal radius to mean epithelial thickness (MLR/MET). Additionally, flesh condition index (FCI) and gonad index (GI) were measured as supporting parameters. In hake and anchovy, liver histopathology was examined to determine the prevalence of parasites, melanomacrophage centers, non-specific lesions (inflammatory changes, atrophy, necrosis, apoptosis), early non-neoplastic toxicopathic lesions (i.e. hepatocellular nuclear polymorphism), foci of cellular alteration, benign and malignant neoplasms (Marigómez et al., 2004). After the *Aegean Sea* oil spill that took place in A Coruña (Galicia) in December 1992 (Solé et al., 1996; Porte et al., 2000, 2001), the levels of total cytochrome P-450, CYP1A-like protein and lipid peroxidation in mussel digestive gland tissue increased along a gradient towards the spill, in parallel with increasing tissue levels of PAHs (Solé et al., 1996; Porte et al., 2000). After the *Sea Empress* oil spill that affected South West Wales in 1996, ethoxyresorufin Odeethylase (EROD) activity in fish (Kirby et al., 1999), CYP1A-immunopositive protein levels, microsomal benzo(a)pyrene hydroxylase activity (Peters et al., 1999), and lysosomal stability of blood cells (Fernley et al., 2000) in mussels and DNA-adduct levels in mussels and fish (Lyons et al., 1997; Harvey et al., 1999) discriminated between areas directly polluted by the spill and reference locations. Likewise, 8 years after the *Haven* oil spill that occurred in the Ligurian Sea in 1991, increased levels of DNA-adducts revealed the presence of genotoxic compounds in two demersal fish species (fourspotted megrim Lepidorhombus boscii and European hake Merluccius merluccius), collected in the sinking area (Pietrapiana et al., 2002). Most data concerning the use of biomarkers to assess biological effects of oil spills have been obtained after the *Exxon Valdez* oil spill that affected Northern Prince William Sound (Alaska) in March 1989. Yet, 10 years after the *Exxon Valdez* oil spill, elevated CYP1A in liver vascular endothelium, liver EROD activity and biliary fluorescent aromatic compounds were recorded in fishes from sites originally oiled (Jewett et al., 2002; Hugget et al., 2003). Moreover, the investigations conducted after the *Exxon Valdez* have shown a linkage between biomarker responses and long-term effects in populations (Peterson et al., 2003). Together with classically recognized biomarkers, fish diseases and histopathology are increasingly used as indicators of pollution effects since they provide a definite biological end-point of historical exposure (Stentiford et al., 2003). Histopathological alterations in selected organs and tissues, mainly gills, liver and gonad, are conceived as histopathological or tissue-level biomarkers. The presence of inflammatory lesions, hepatocellular fibrillar inclusions, and preneoplastic (i.e. hepatic foci of cellular alteration) and neoplastic lesions is higher in fish captured in polluted sites than in those from reference sites (Stentiford et al., 2003). The occurrence of tumors in wild fish has been used frequently as an indicator of environmental carcinogens such as PAHs in pollution monitoring programs (Wester et al., 2002). Additionally, a pivotal factor in health and survival is the quality of the immunological defense system, which may be affected by toxic chemicals (Wester et al., 2002). A weakened immune system renders fish more susceptible to develop toxicological lesions and to be more easily parasitized. Xenobiotic metabolization can lead to reactive compounds able to interact with DNA to form DNA adduct. The presence of a DNA adduct in a critical gene provides the potential for occurrence of a mutagenic event, resulting in subsequent alterations in gene expression and a loss of growth control (for a review see Poirier and Beland, 1992). DNA adducts formation have already been reported *in vivo* both in fishes and in mussels exposed to the *Erika* oil spill (Amat et al., 2004a,b, 2005, 2007).

Articles in this section are sorted firstly in a section of general literature on studies carried out on oil pollution and the ecology of different organism; secondly in a repartition by major accidents, divided by sea.

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➢ Other Extra European accidents

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2.1.2 Effects of oil spills on different ecosystems

Sea Water

Open waters of the oceans and the associated pelagic and seabed communities have rarely shown any impact from spills. The high diluition potential that this habitat provides is a major mitigating factor. Even though laboratory research has shown that planktonic organisms which live in surface waters can be variously affected by oil, no long-term effects have been demonstrated due to their huge regenerative potential, as well as immigration from outside the affected area. This regenerative potential is fundamental to the important role the plankcton plays in the food chain of the world's seas and oceans (Dicks, 1999).

Concerns are often expressed about the effects of spills on fish and shellfish eggs and larvae which are found in the plankton, especially as their sensitivity to oil pollution has been demonstrated with toxicity tests. However, there is no definitive evidence that oil induced mortalities of fish and shellfish egg and larvae in the open sea have resulted in significant effects on future adult populations. This is not surprising because oil-induced mortalities of egge and young life stages are often of little significance compared with huge natural losses each year (e.g. through predation, temperature changes or storms) (Dicks, 1999).

Probably, the most vulnerable of the organisms which use open waters are sea birds, which are easily harmed or killed by floating slicks. Although oil ingested during preening may be lethal, the most common cause of death is from drowing, starvation and loss of body heat following damage to plumage by oil. Nevertheless, research has rarely shown any detectable impact from spills on breeding populations, even when mortalities from oil contamination are known to have been high. Shore birds, notably waders, are also at risk though are less likely to become seriously and lethally oiled than seabird that live and feed on the open sea (Dicks, 1999).

Whales, dolphins and seals in the open sea are not particularly at risk from oil spills. Marine mammals that breed on shorelines are, however, more likely to encounter oil. Species at particular risk are those which rely on fur for conservation of body heat (e.g. otters). if the fur becomes matted with oil, they cannot regulate their body heat and may die from hypothermia or overheating (Dicks, 1999).

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Marine Sediments

If sediments are penetrated by the oil, then considerable quantities may be held and the likelihood of long-term retention and long-term impacts is greatly increased. However, the more viscous nature of weatherd oils may result in reduced penetration compared to fresh, less viscous crudes (Dicks, 1999).

The effects of the 1992 *Aegean Sea* spill on the infralittoral muddy-sand macrobenthic communities of the Ares and Betanzos Ria in Galicia (Spain) were monitored in detail over a four-year period (1992-1996) (Mora et al., 1996a,b; Gomez Gesteira, 2001). These studies revealed strong similarities with the impact of the *Amoco Cadiz* oil spill on the infralittoral communities of the Bay of Morlaix (Western English Channel). The comparison of these two spills has revealed general patterns in the effects of oil on soft-bottom macrobenthic species and populations (Gomez Gesteira and Dauvin, 2000).

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Shorelines

Shorelines, more than any other part of the marine environment, are exposed to the effects of oil as this is where it naturally tends to accumulate. The degree of oil retention by a shore considerably affects the short-term impact and duration of damage. Retention depends upon the condition of the oil and beach type (e.g. rock, sand, shingle, mud flat, tidal flat,…see below). More viscous oils tend to be retained in greater quantities as surface accumulations than less viscous oils. Broken, uneven and gently sloping shorelines with a large tidal range can hold more oil than steep, smooth shore with a small tidal range (Dicks, 1999).

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Rocky shores

Rocky and sandy shores which are exposed to wave action and the scouring effects of tidal currents are amongst habitats which are more resilient to the effects of a spill, and they tend to self-clean relatively rapidly. These shorelines often have communities of highly adapted species, especially grazers and filter-feeders. If grazers are killed by oil, seaweeds rapidly settle, followed by a slow return of grazers by recolonisation and new recruitment. Recovery to an apparently normal balance is often achieved in 1-5 years, but the complete re-establishment of a shore can take many years in extreme situations where very large areas are affected or where species are close to the limits of their geographical range and recolonisation proves to be slow (Dicks, 1999).

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Beaches

Exposed beaches are considered poor habitats where wave action and the instability of the sediment limit the development of animals and plant communities, with low productivity compared with other coastal environments (rocky shores, subtidal sediments, saltmarshes...). Sandy beaches were hardly studied until the 1970s, when the importance of the animal communities linked to these beaches was demonstrated. The biology and the distribution of the species on the beaches are linked with their location in terms of the tide, with a typical layout in all intertidal communities, i.e. zonation or distribution on tidal horizons. The effect of hydrocarbon contamination on beaches is especially detrimental to the upper tidal zones, these generally being near to the base of dunes or cliffs surrounding the beach. The dominant fauna in these areas (isopods and amphipods) display semi-terrestrial ecological and physiological characteristics and direct embryonic development, i.e. they lack the larval phase of dispersion so that females transport embryos until they become individuals morphologically similar to the adults, but smaller in size, remaining in the same habitat as their forebears. Thus, the populations of these species affected by contaminant spillage are unable to recover easily from ''imported'' recruits coming from other more or less neighbouring populations. This highlights the extreme sensitivity of the upper levels of beaches, underlining how important it is to study and to preserve them.

Presence of oil contaminants in sand changes, also, its fluidization behaviour. There is a percentage of pollution in the bed above which the bed is not fluidizable, which varies with the type of pollutants in the bed and the type of sand in use. While heavy oil pollution was critical for the coarse sand, the light oil pollution was critical for the fine sand. Presence of water worsened the scenario in all the cases.

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Tidal flats and Salt marshes

Tidal flats are broad, low-tide zones, usually containing rich plant, animal, and bird communities. Deposited oil may seep into the muddy bottoms of these flats, creating potentially harmful effects on the ecology of the area. Salt marshes are found in sheltered waters in cold and temperate areas. They host a variety of plant, bird, and mammal life. Marsh vegetation, especially root systems, is easily damaged by fresh light oils. Salt-marshes, although generally only temporarily harmed by single oilings, can take more than 10 years to recover if damaged through repeated oilings. However, long-term damage is more usually the result of using inappropriate clean up techniques than as a direct consequence of oiling (Dicks, 1999).

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Subtidal sediments

A common feature of major spills in coastal areas are sites where, because of the topography and the action of various physical processes, the shorelines are heavily oiled. Hydrocarbon concentrations in the intertidal regions of these sites can be as high as 10000 to 30000 ~tg g-i (Gundlach et al., 1983; Page et al., 1989; Sauer et al., 1993). The question often arises after such spills as to the extent and effect of oil entering the subtidal zones. Estimates made on the relative amount of the oil entering the subtidal zones after spills include the following: 1. 8% for the *Amoco Cadiz* on the Brittany Coast (English Channel), France (Gundlach et al., 1983); 2. 3-6% for the *Tsesis* spill in the Baltic Sea, Sweden (Linden et al., 1979; Johansson et aL, 1980); 3. 13% for the *Exxon Valdez* spill in Prince William Sound, Alaska (Wolfe et al., 1994); 4. 0.5-3% of the oil from the Ixtoc blowout in the Gulf of Mexico (Boehm and Fiest, 1982). These estimates suggest that the total volume of oil entering the subtidal regions after spills can be quite high. However, as discussed in this paper, it is not the total amount of oil which is important when evaluating the possible biological effects, but the types and concentrations of hydrocarbons in the subtidal sediments. It appears that in most large oil spills, the hydrocarbon concentrations in the subtidal regions are many orders of magnitude lower than heavily oiled intertidal regions.

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Estuaries

Fine sediments (fine sand and mud) are usually found in more sheltered areas, and tend to be highly productive, particularly in estuaries.
The more invisible release of oil and its toxic compounds in nature is probably of even greater concern to us, especially since about one third of all oil released is ultimately accumulating in estuaries (Kennish, 1992), that contain a wide range of very fragile environments. Estuaries support large populations of migrating birds as well as shell fisheries and also function as nursery areas for some species. Whilst oil can exert immediate toxic and smothering effects, penetration of the oil to deeper layers is rare, especially if sediments remain waterlogged during low tide. However, there have been cases of oil penetrating into animal burrows, and once oil is incorporated within the sediment it can delay natural recovery (Dicks, 1999).

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Rivers

River habitats may be less severely affected by spills than standing water bodies because of water movement. However, spills in these water bodies can affect plants, grasses, and mosses that grow in the environment. When rivers are used as drinking water sources, oil spills on rivers can pose direct threats to human health.

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2.2 Literature collection on the Management of oil spills

Chemical-Physical Processes

Crude oil and oil-spill-related samples are extremely complex mixtures in which the components range from simple alkanes to complex asphaltic components, the boiling points of which vary over a wide range from a few to several hundred degrees.

As soon as oil is spilled into the environment the processes of volatilization, dissolution, microbial and photochemical degradation act to change its composition. Consequently, the chemical analysis methods employed should yield sufficient accuracy and compositional detail (especially with respect to the key toxic compounds, because the effects of spilled oil on the environment are strongly related not only to the gross amount of oil, but also to the levels of those key toxic compounds) to answer the specific questions to be answered in an environmental assessment study.

For weathering studies, monitoring the changes in the chemical composition of the spilled oil is of crucial importance, especially when there is a prolonged period of weathering (Wang et al., 1995).

In most cases, the oil, after release into the environment, is immediately subjected to a wide variety of weathering processes (Jordan et al., 1980) including evaporation, dissolution, dispersion, photochemical oxidation, water.oil emulsification, microbial degradation and adsorption onto suspended particulate materials.

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Risk Management

In view of the quantity of oil spilled, smaller spills generally receive less attention than headline grabbing incidents such as the *Amoco Cadiz*, *Exxon Valde*z, *Braer* and *Sea Empress*. The latter incidents involve the loss of significant quantities of oil, the establishment of relatively complex spill response management structures and the partecipation of significant numbers of personnel and equipment. As large spills from tankers have the potential to create problem areas, for example in establishing and maintaining effective communications, logistics and resource management systems are required.
Making and updating sensitivity maps are key activities and useful tools in the planning processes. These maps convey essential information to spill responders by showing where the different coastal resources are and by indicating environmentally sensitive areas. The making of a map involves assembling information on commercial, ecological and recreational resources and deciding what guidelines for spill response may be included. Mapping may be either paper based or link into a geographic information system (GIS) to provide a comprehensive tool to advice and support decision makers. A wide range of contingency planning information can be included within a GIS (e.g. equipment stockpiles, environmental sensitivities, response procedures, trajectory modelling etc.), but care has to be taken to avoid paper maps becoming too cluttered and difficult to interpret. The maps could show the agreed response tactics for each zone (sandy beaches, gravel beaches, rocky shores, mud flats….). Priorities for protection should be agreed with the involved administrations and agencies. Maps can then be annotated to show the priority level attributed to each zone. Authorized access points and possible temporary storage areas may also be identified on the maps (IPIECA, 2000).
An interesting study was carried out during 1999-2002 and dealt with the identification of the environmental sensitivity of the Mediterranean coastline of Israel to marine oil spills (Adler and Inbar, 2007). It includes GIS sensitivity mapping and an analysis of the environmental vulnerability of Israel's shoreline resources. The study analyses the main sources of risk for maritime accidents in the southeastern Mediterranean and develops scenarios for possible oil spills incidents, including an analysis of the priorities for protection of the various coastal ecosystems, in an event of a large spill. It describes the morphology of the coastline of Israel, as well as the main hydrographic and meteorological patterns that dominate and control the dynamics of the shorelines, and of potential major oil spills. The study also discusses the different ways in which oil spills may affect natural ecosystems and socio-economic resources along the coastline of Israel. The basic research question of the study was how different geomorphic and land-use types of the Mediterranean shoreline would be affected by large quantities of spilled oil washing ashore from the sea. The study aimed at determining the relative sensitivity of different types of shoreline and 'prioritizing' the different types of shoreline and coastal resources to be protected following a large oil spill. The study also aims at presenting the data collected and analyzed to both the scientific and National authorities responsible for oil spill preparedness and response, in a clear and useful way.
Another important aspect of management is represented by a prompt response from oil spill response managers to the operational and administrative problems (e.g, moving personnel and

equipment and at the same time providing human health and safety, implementing communications, logistics and equipment issues…).

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3 Bibliography summary

From this report of the literature it is concluded that the *Exxon Valdez* and *Amoco Cadiz* present the highest number of publications (203 and 127, respectively), followed by *Prestige* (75), *Sea Empress* (50), *Erika* (41), *Braer* (26), *Haven* (17) and *Aegean Sea* (13) (Figure 7). These mainly refer on topics concerning the impacts on the coastal environment and the management aspects of some of the major oil spills. Other publications dealing with clean up techniques, oceanography modelling and remote sensing were not considered in this report, being the objectives of other reports. The major number of publications on the *Amoco Cadiz* and *Exxon Valdez* is due both to the great impact and environmental pollution derived from these spills and because they are among the first reported accidents of large proportions. It is worth to notice that, although the *Exxon Valdez* accident occurred in 1989, the scientific interest concerning the recovery of the environmental damage and the long term environmental effects are still of primary interest for the research community, as demonstrated by the recent literature published on this subject.

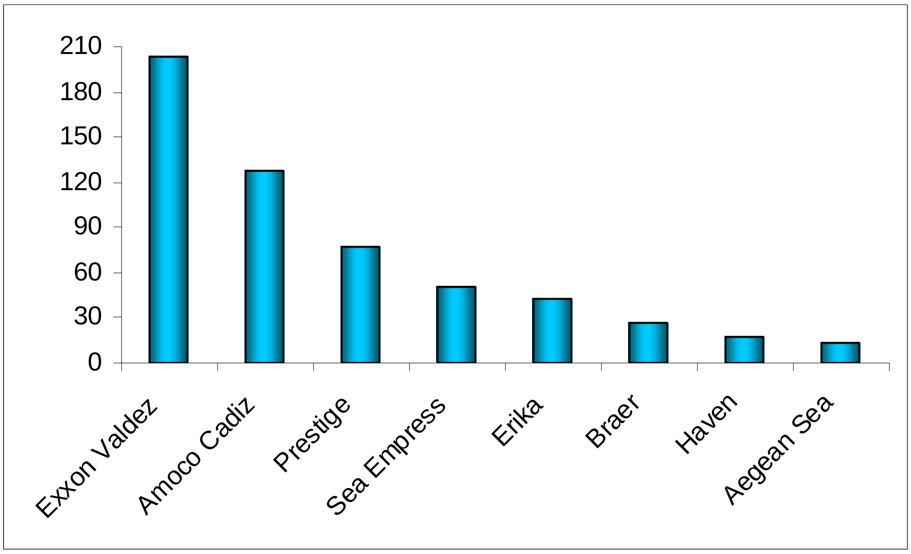

Figure 7: numbers of papers for some of the major oil spills.

In Europe, whose coasts have been affected by a great number of oil spills due to tanker accidents, major research works have been carried out on the *Amoco Cadiz* and the *Prestige*, as reviewed in two special issues of *Marine Pollution Bulletin*: (Volume N° 9 (Issue 11) published in 1978 and Volume N° 53 (Issues 5-7) published in 2006).

Currently, the *Prestige* oil spill constitutes a milestone study case in aquatic toxicology. The persistence of its chemical constituents, the extent of the spill over the time (over 1 year after November 2002), the extension of the area affected in Bay of Biscay (from Galicia to Brittany) and the economical relevance of fisheries and shellfish culture in the area affected renders the *Prestige* oil spill a unique episode in marine pollution. It is conceivable that further noteworthy effects on the ecosystem, other than massive killing during the black tide episode will be detected only after several years.

According to a deeper bibliographic analysis of some important oil spills (*Amoco Cadiz*, *Exxon Valdez*, Prestige, *Aegean Sea, Braer, Sea Empress, Erika* and *Haven*) the most investigated field deals with the study of multiple environmental impacts. Studies on the effect of oil spills on the ecology of marine organisms have received a lot of effort by the scientific community, with the aim to investigate both short term and long term consequences of spills at different ecological scales (from the cells to the ecosystem). Other minor research fields to which a different importance was given accordingly to the specific situation are reported in Figure 8.

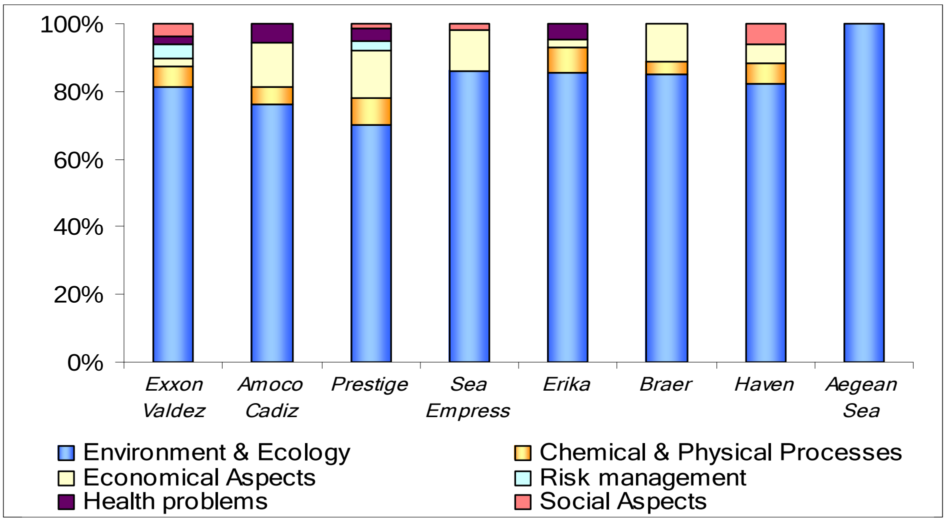

Figure 8: Relative frequency (%) of the different fields of study.

Considering the literature on the environmental and ecological impacts the main studied subjects resulted to be Pelagos, Benthos, both intertidal and subtidal, Birds, Marine Mammals and Ecotoxicological Assay, as shown in Figure 10. A specific serie for Mussels it is included, because of their importance and frequent use as bioindicators (Figure 10). A large number of studies publicated so far have been focused on benthic communities. The sediment is considered a key compartment in environmental impact studies as it functions as a recorder of water column processes. The benthos includes most commonly used bioindicators of environmental changes (eg macrofauna); it is composed by species with a very wide distribution that play an important functional role in the ecosystem and by commercially-important species that involve public health issues too. In Figure 9 is reported an overview of the main motivations reported by the Cedre in the case of benthic studies.

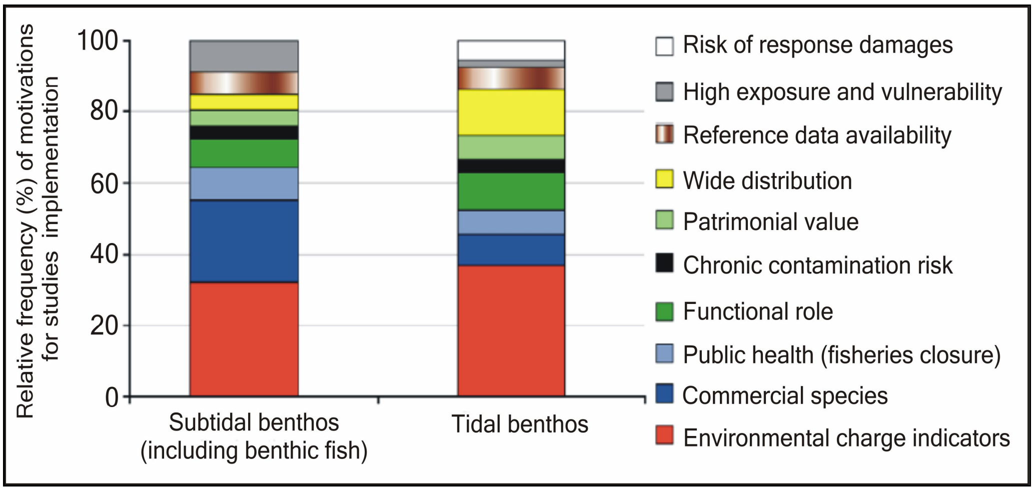

Figure 9: reported an overview of the main motivations reported by the Cedre in the case of benthic studies (source: Calvez, 2007).

Sometimes, as in the case of the *Braer* accident, pelagic organisms received more attention. This is related to the effect of weather conditions that spread the oil slick on a wide area, with deleterious effects on the pelagos, expecially fish.

It is notable how, differing the environmental characteristics, target organisms significantly differ from an accident to the others. After the *Exxon-Valdez* oil spill, for example, main attention was given to the effects of oil to the pink salmon, due to its great importance both at ecological and economical level. Again in the case of the *Exxon-Valdez*, some papers dealed with the ecological impacts of oil on mammals, present with high population densities in this part of the Pacific Ocean. Mammals were also studied following the oil spill accident of the *Erika*.

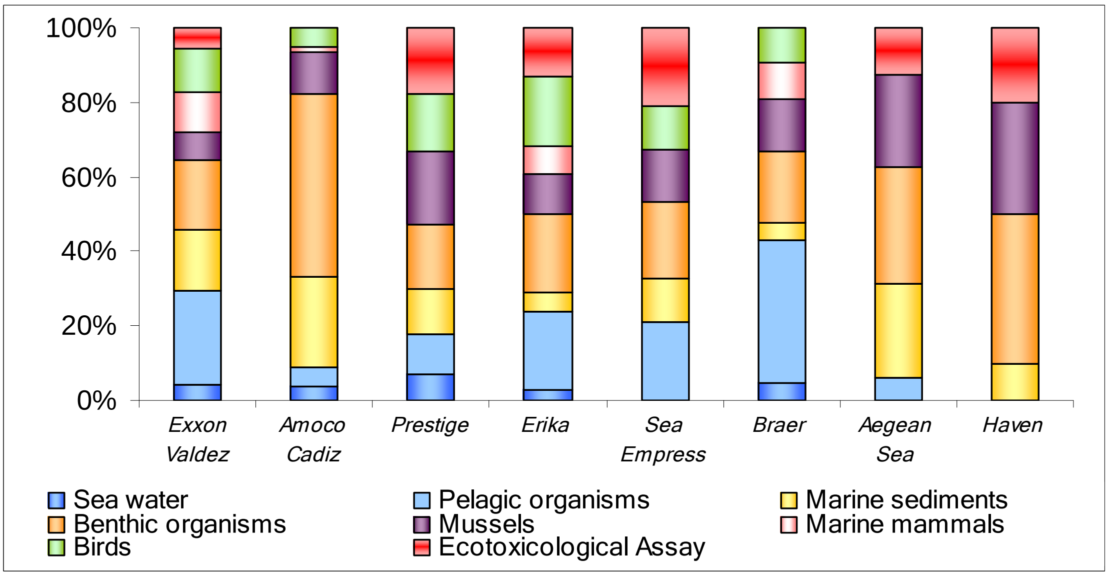

Figure 10: Relative frequency (%) of the domains analysed in environmental impact assessment studies.

In particular, the minimum and maximum percentage values are:

- ✓ Benthos (sediment + organisms) 3-35%
- ✓ Pelagos (seawater + organisms) 0-30%
- ✓ Birds 0-12%
- ✓ Marine mammals 0-10%
- ✓ Mussels 2-7%
- ✓ Ecotoxicological Assay 0-6%

Table 7: Comments on the main effects of oil on different groups of plants and animals (modified from IPIECA, 1991).

GROUP	EFFECTS
Plancktonic organisms	Serious effects on plankton have not been observed in the open sea. This is probably because high reproductive rates and immigration from outside the affected area counteract short-term reductions in numbers caused by the oil.
Invertebrates	Invertebrates include shellfish (both molluscs and crustaceans), worms of various kinds, sea urchins and corals. All these groups may suffer heavy casualties if coated with fresh crude oil. In contrast, it is quite common to see barnacles, winkles and limpets living on rocks in the presence of residual weathered oil.
Larger algae	Oil does not always stick to the larger algae because of their mucilaginous coating. When oil does stick to dry fronds on the shore, they can become overweight and subject to breakage by waves. Intertidal areas denuded of algae are usually readily re-populated once the oil has been substantially removed.
Fish	Eggs and larvae in shallow bays may suffer heavy mortalities under slicks, particularly if dispersants are used. Adult fish tend to swim away from oil. There is no evidence so far that any oil spill has significantly affected adult fish populations in the open sea. Even when many larvae have been killed, this has not been subsequently detected in adult populations, possibly because the survivors had a competitive advantage (more food, and less vulnerable to predators). Adult fish in fish farm pens may be killed, or at least made unmarketable because of tainting.
Birds	Birds using the water-air interface are at risk, particularly auks and divers. Badly oiled birds usually die. Recovery of populations depends either on the existence of a reservoir of young non-breeding adults from which breeding colonies can be replenished (e.g., guillemots) or a high reproductive rate (e.g., ducks). There is no evidence so far that any oil spill has permanently damaged a seabird population, but the populations of species with very local distributions could be at risk in exceptional circumstances.
Mammals	It has been rare for whales, dolphins, seals and sea lions to be affected following a spill. Sea otters are more vulnerable both because of their way of life, and their fur structure.

Regarding environmental compartments, the greater number of published studies concerned *off-shore* sediments, (on average 38% of the literature). In the case of the *Exxon Valdez* many studies were carried out on the sublittoral and shoreline sediments and on beaches, while rocky shores are the main environment investigated after the *Sea Empress* and the *Erika* oil spills (Figure 11, 12).

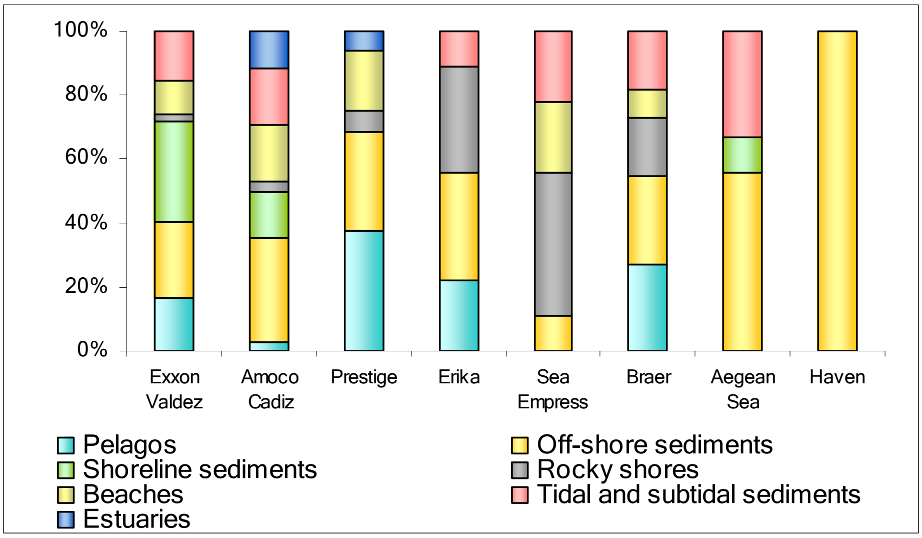

Figure 11: Relative frequency (%) of the ecosystems analysed in environmental impact assessment studies.

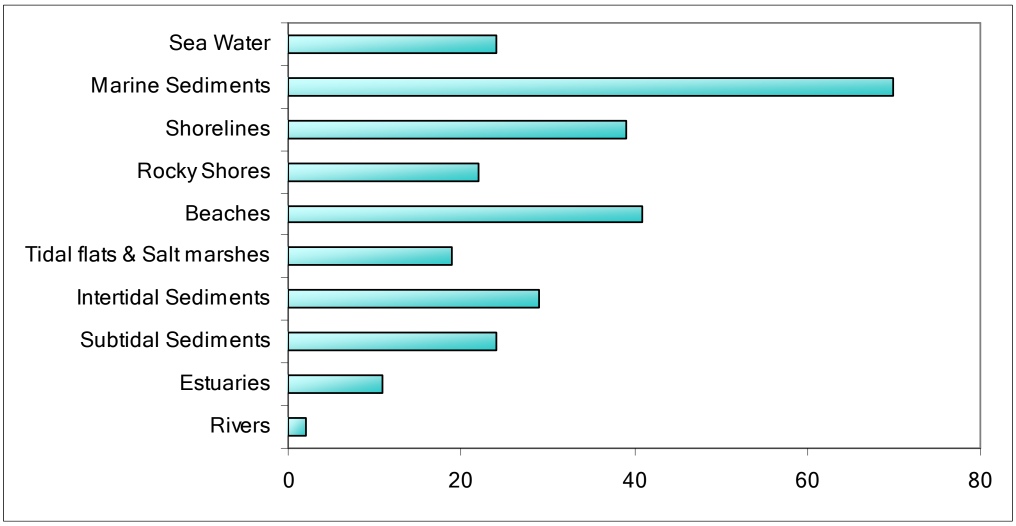

Figure 12: number of papers related to the different domains.

Concerning the Northern hemisphere, the North East Atlantic region is the area with the highest number of published studies on the ecology and on the management of oil spills (Figure 13). Of course this is related to the great number of accidents occurred in this area (Figure 2). For the Pacific Ocean only the studies on *Exxon Valdez* oil spill were considered.

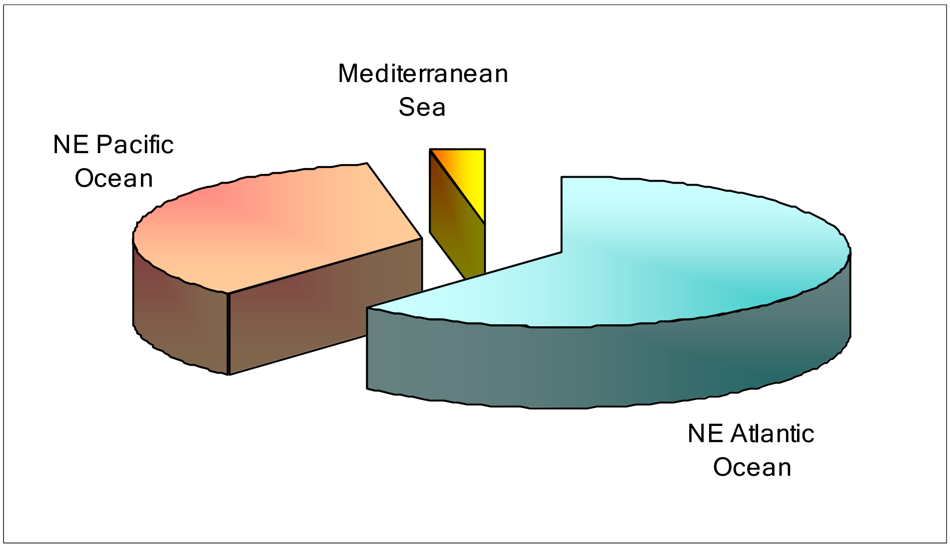

Figure 13: Relative frequency (%) of studies on oil spills occurred in the three Oceans/Seas considered.

In conclusion, from the analysis of the literature reported some key issues can be underlined:

- In the last years, it is remarkable an increasing interest of the scientific community on the problems related to the characterisation of chemical compositions and identification of oil spill sources, through chemical "fingerprinting". This technique is really important for assessing the toxicity and the consequent biological impact of the oil and also for settling disputes related to liability.
- Biological effects of oil spills are generally extremely hard to predict. The initial environmental impact derived from an oil spill, in fact, can vary from minimal (e.g., following some open ocean spills) to the death of everything in a particular biological community. This can be mainly referred to several factors, such as spill size, type of the oil, location (closeness to shoreline), time of year, atmospheric as well as oceanic conditions.
- For what concerns the effects of oil on different habitats, oil slicks in the open sea usually disperse, and some large spills (e.g., the *Argo Merchant* and the *Ekofisk* Bravo blowout) have caused minimal ecological damage for this reason. Moreover, oil toxicity is reduced as the oil weathers. Thus a crude oil spill which reaches a shore quickly will be more toxic to the shore life than if the slick has been weathering at sea for several days before stranding. For example, oil from the *Exxon Valdez* spill in Alaska was relatively well weathered by the time it reached most shores.
- Close to the shore, damage is likely to be more pronounced in sheltered shallow water bays and inlets, where oil in the water may reach higher concentrations than in the open sea. This is also likely to be true of estuarine and some riverine ecosystems. On the shore there is a range of possibilities concerning the fate and effects of oil. These are bound up with two important variables: the energy level of the shore (degree of exposure to wave energy) and substratum type. On exposed rocky shores, effects on shore life tend to be minimal and recovery rates rapid because oil does not stick easily to such shores. Even if some does, it is likely to be quickly cleaned off by vigorous wave action. With increasing shelter of rocky shores, the likelihood of oil persisting increases, as does the algal biomass with its capacity to trap oil. The most sheltered shores tend to be sedimentary, with mud flats and marshes. Such vegetated areas have a high biological productivity but are also the worst oil traps, and are therefore of particular concern following spills.